Geochemical Characteristics of the Devonian Woodford Shale

Dan Jarvie

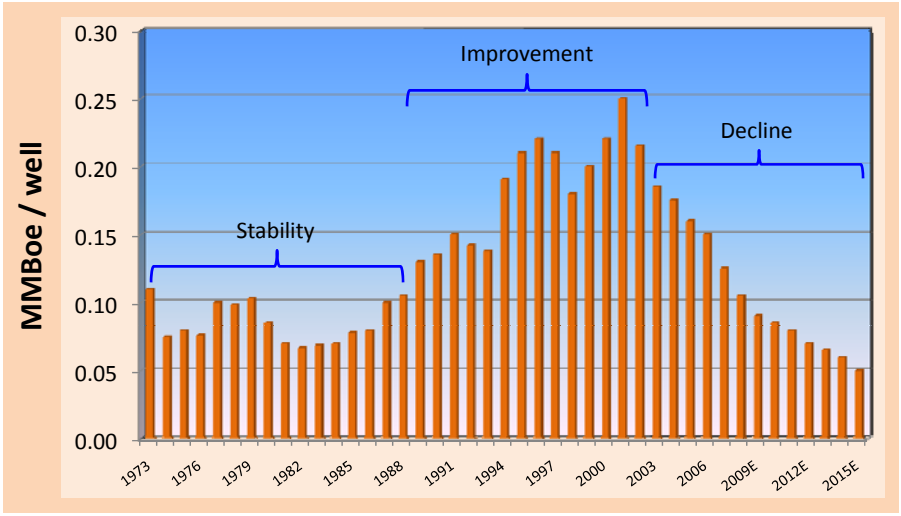
Worldwide Geochemistry, LLC

Outline

- Background
- Woodford Shale Geochemistry
- Woodford Shale-Gas
  - Oklahoma
    - Arkoma Basin
    - Anadarko Basin
    - Ardmore Basin
  - Texas
    - Permian Basin
- Woodford Shale Oil
- Summary

Reserves per Well Declining but offset by drilling more wells

Reserves per well added, 1973-2015 est.

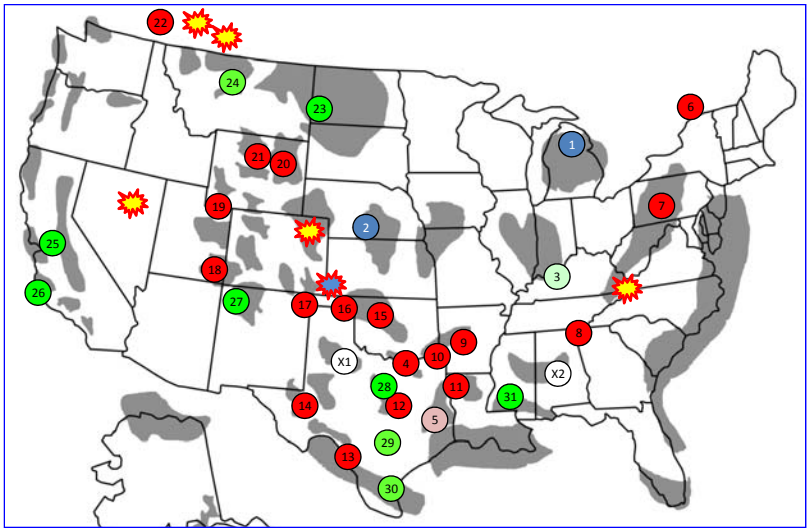


Sources: EIA; Bernstein Estimates

Where is the most likely place in a sedimentary basin to find hydrocarbons ?

The source rock

North American Shale Resource Plays



Geochemical Data
on various shale resource play types

Shale	Interpreted Thermal Maturity Window	TOC (wt.%)	Estimated TOC_o (wt.%)	HI mg HC/g TOC	Estimated TR	$\%R_{oe}$ from Tmax	Measured $\%R_o$	S1/TOC mg HC/g TOC	Count	Dry Gas Ratio (C1/(C1..C4))	$\delta^{13}C$ methane (ppt)	$\delta^{13}C$ ethane (ppt)	$\delta^{13}C$ propane (ppt)
Antrim	Immature to early oil	5.27	5.35	432	10-20%	0.67	0.51	53	181	98%	-55		
New Albany	Oil	7.06	7.28	428	5-40%	0.65	na	21	59	52%	-53	-44	-37
Woodford	Oil	9.23	9.61	503	10-50%	0.76	0.54	52	31				
Marcellus	Dry gas	3.37	5.27	16	>90%	2.16	na	20	33				
Utica	Dry gas	1.71	2.67	18	>90%	nr	na	33	21				
Fayetteville	Dry gas	1.86	2.91	24	>90%	nr	2.0-2.5	15	538				
Woodford	Late oil-early gas	2.04	3.19	73	>80%	0.92	na	17	40				
Barnett	Immature-early oil	5.21	5.37	380	12%	0.62	0.55	42	3				
Barnett	Early oil	4.70	5.28	299	31%	0.86	0.77	78	25				
Barnett	Gas	4.45	6.50	45	90%	1.72	1.67	19	90				
Atokan	Late oil-early gas	3.11	4.86	23	>70%	1.4	na	27	18				
Barnett	Late oil-early gas	4.04	6.31	67	>70%	0.76 - 1.48	0.86-2.15	33	858				
Woodford	Late oil-early gas	3.93	6.14	87	>70%	1.02	1.20 - 2.10	70	32				
Bossier	Dry gas	1.81	2.83	13	>90%	nr	1.40	18	28				
Lewis	Dry gas	1.46	2.28	22	>90%	NR	1.60	18	22				
Waltman	Oil	2.53	4.22	322	50%	0.75	0.69	5	43	97%	-35	-23	-22
Bakken	Oil	11.37	13.87	298	10-70%	.50 - 1.00	0.55 -0.95	43	349				
Monterey	Oil	6.77	7.96	460	10-20%	0.40	0.45	88	12				
Antelope	Oil	3.02	3.18	433	10-30%	0.55	na	70	70				

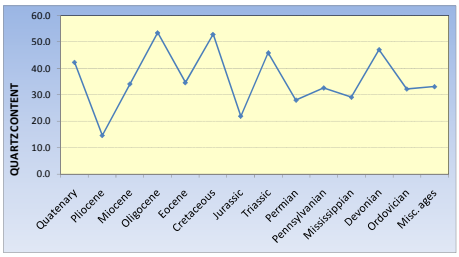
All values are average values from Humble database and may include variable thermal maturities

TOC_o	total organic carbon, original value
HI	hydrogen index (S2/TOC x 100; mg HC/g TOC)
TR	transformation ratio $((HI_o - HI_{pd})/HI_o)$ where HI_o is original HI and HI_{pd} is present-day HI value
$\%R_o$	vitrinite reflectance in oil submersion
$\%R_{oe}$	vitrinite reflectance equivalent; calculated from Rock-Eval Tmax value
ppt	parts per thousand or parts per mil

Shale Composition

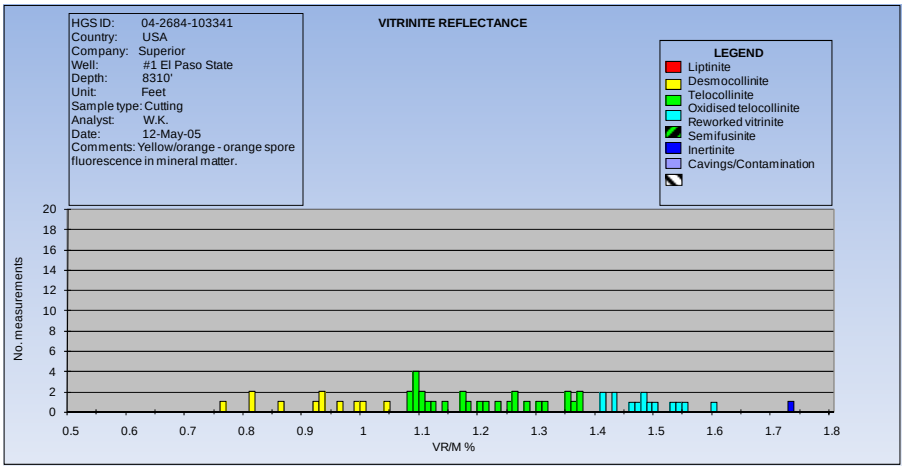
Age	Count	Clay Minerals	Quartz	Potassium Feldspar	Plagioclase Feldspar	Calcite	Dolomite	Siderite	Pyrite	Other
Quatenary	5	29.9	42.3	12.4	0.0	6.6	2.4	0.0	5.6	0.8
Pliocene	4	56.5	14.6	5.7	11.9	3.2	0.0	2.9	1.8	3.4
Miocene	9	25.3	34.1	7.8	11.7	14.6	1.2	0.0	1.9	3.4
Oligocene	4	33.7	53.5	3.0	0.0	5.5	0.0	0.0	0.0	4.3
Eocene	11	40.2	34.6	2.0	8.1	3.8	4.6	1.7	1.6	3.4
Cretaceous	9	27.4	52.9	3.6	1.6	2.9	7.9	0.1	1.6	2.0
Jurassic	10	34.7	21.9	0.6	4.4	14.6	1.6	0.4	10.9	10.9
Triassic	9	29.4	45.9	10.7	0.7	3.7	4.1	5.1	0.0	0.4
Permian	1	17.0	28.0	4.0	8.0	0.0	1.0	0.0	0.0	42.0
Pennsylvanian	7	48.9	32.6	0.5	6.2	1.4	2.1	3.4	3.5	1.4
Mississippian	3	57.2	29.1	0.4	2.9	0.0	0.0	0.6	5.1	4.7
Devonian	22	41.8	47.1	0.6	0.0	2.0	1.3	0.3	3.3	3.6
Ordovician	2	44.9	32.2	1.0	6.3	9.5	0.5	0.5	3.4	1.7
Misc. ages	29	47.8	33.1	1.0	5.5	5.2	2.3	0.8	3.1	1.2

Average Clay: 38%
Average Quartz: 36%

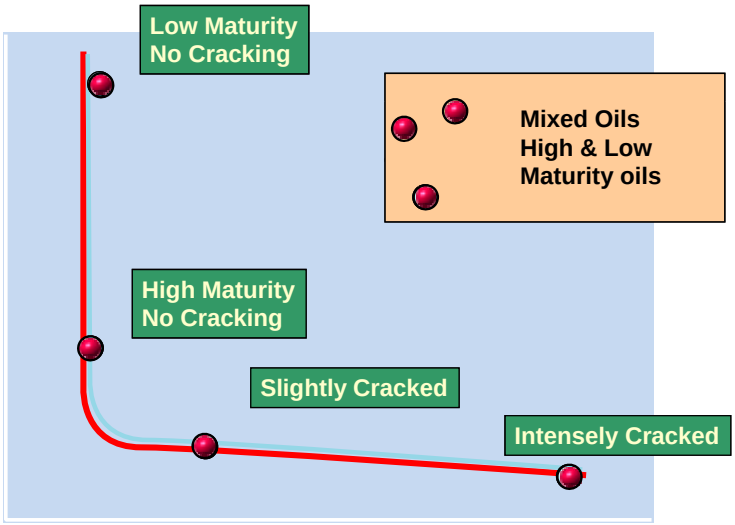


O'Brien and Slatt, 1990

Woodford Shale, Delaware Basin, Texas:
abundance of low reflecting desmocollinite

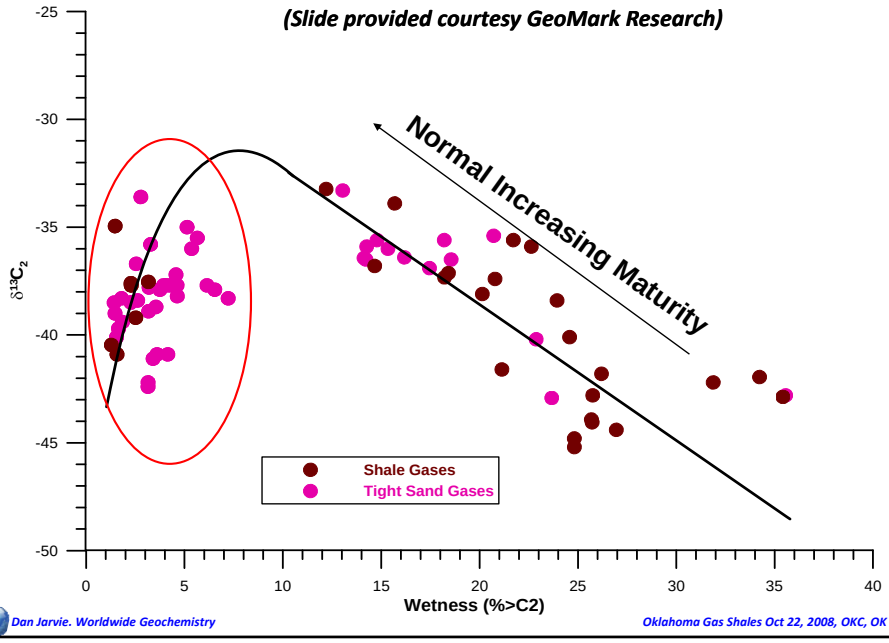


Diamondoids allow for recognition of oil cracking and mixing



Barnett Shale Gas Data

(Slide provided courtesy GeoMark Research)

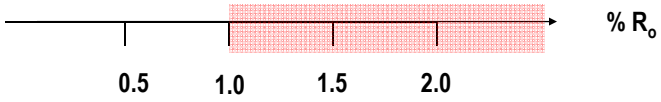


Dan Jarvie. Worldwide Geochemistry

Oklahoma Gas Shales Oct 22, 2008, OKC, OK 10

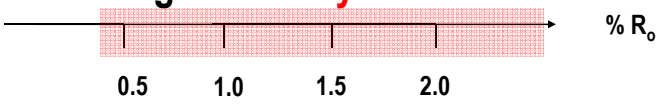
Thermal Decomposition

Kerogen → Oil → Gas → Dry Gas

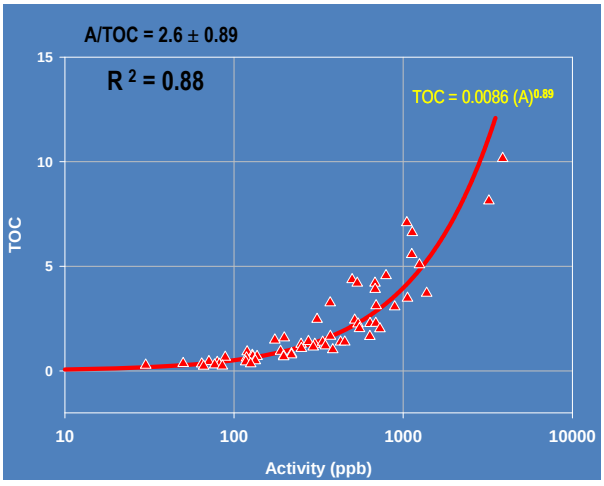


Catalytic Decomposition

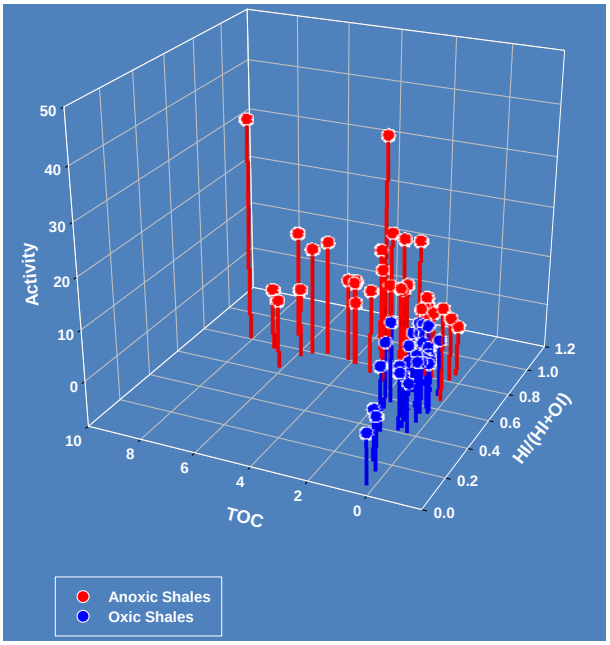
Kerogen → Dry Gas



Catalytic Activity in Shales



Catalytic Activity is related to Hydrogen Index



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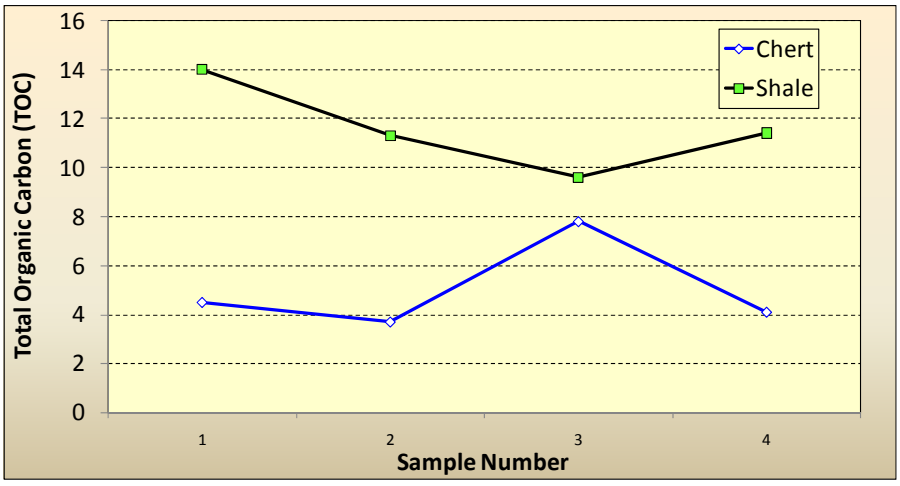
Comparison of Resource Potentials of Mississippian and Devonian Shales

Geochemical Data	Mississippian				Devonian			
	Barnett Shale	Caney Shale	Fayetteville Shale	Floyd Shale	Woodford Shale *	New Albany Shale	Ohio Shale	Chattanooga Shale
Estimated average original TOC	5.84	5.01	5.51	5.65	15.45	13.54	8.34	11.47
Estimated average original generation potential (mg/g)	29.75	19.8	23.9	21.98	59.68	73.81	38.52	42.32
Estimated average total generation potential (bo/af)	651	433	523	481	1306	1616	843	926
Estimated average total generation potential (mcf/af)	3907	2601	3139	2887	7838	9694	5059	5558
Thickness (feet)	100	100	100	100	100	100	100	100
Total generation potential (bcf/section)	250	166	201	185	502	620	324	356
Estimated GIP with 15% retained hydrocarbons	38	25	30	28	75	93	49	53

(comparison made assuming all are 100 ft. thick)

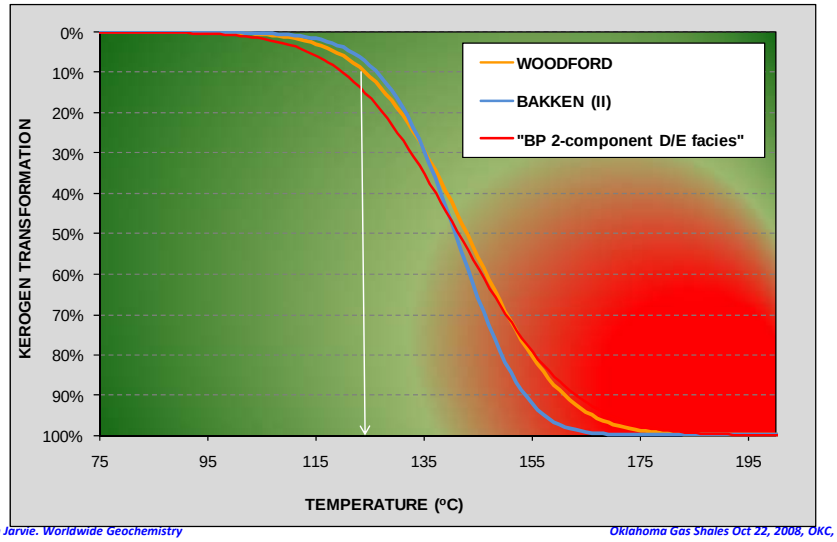
* Ardmore Basin low maturity Woodford Shale outcrops

Comparison of TOC Values: Chert vs. Shale

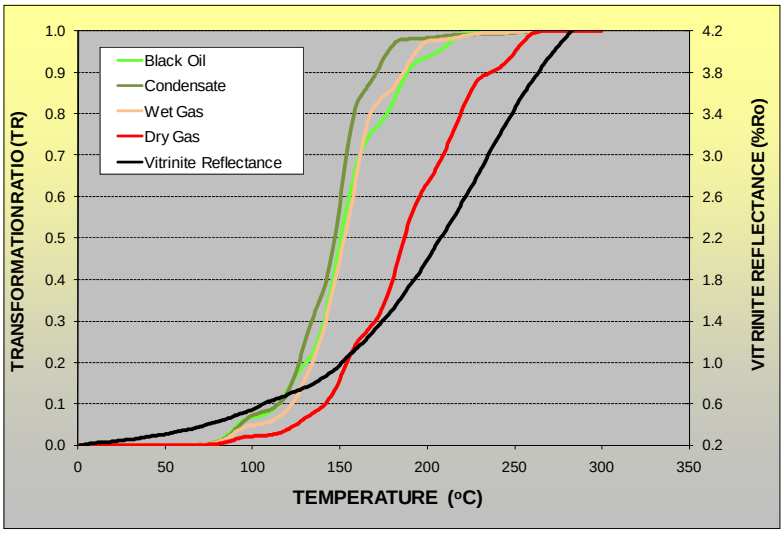


Data from Comer and Hinch, 1987

Oil and Gas Decomposition Profiles low sulfur marine shales

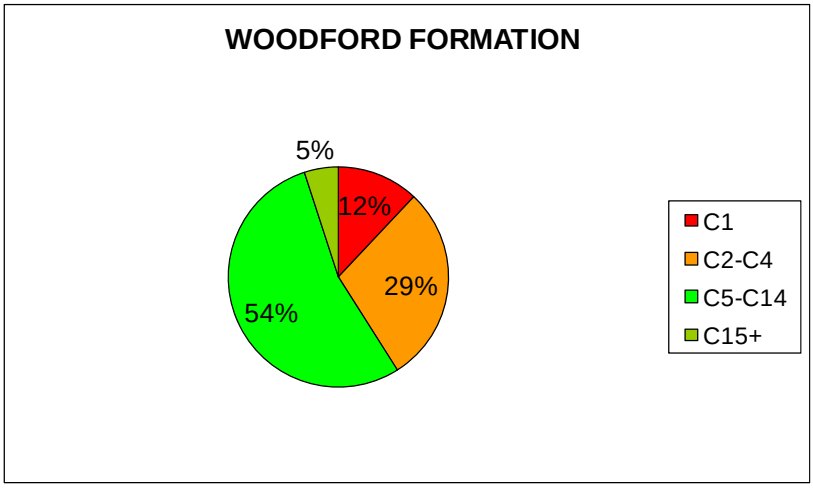


Primary Cracking of Organic Matter in Woodford Shale: Compositional Kinetics

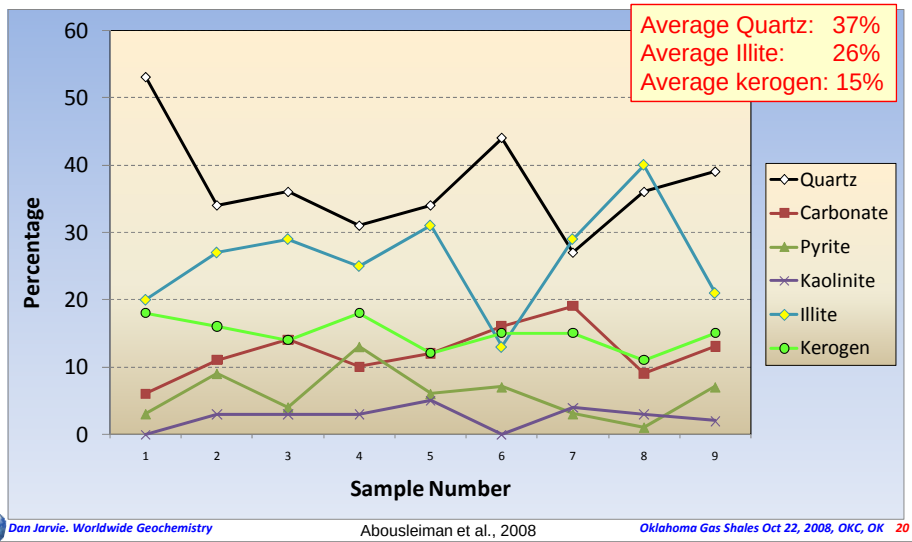


Woodford Shale: Sample A

Oil and Gas Yields upon total decomposition



Woodford Mineralogy: Example



Abousleiman et al., 2008

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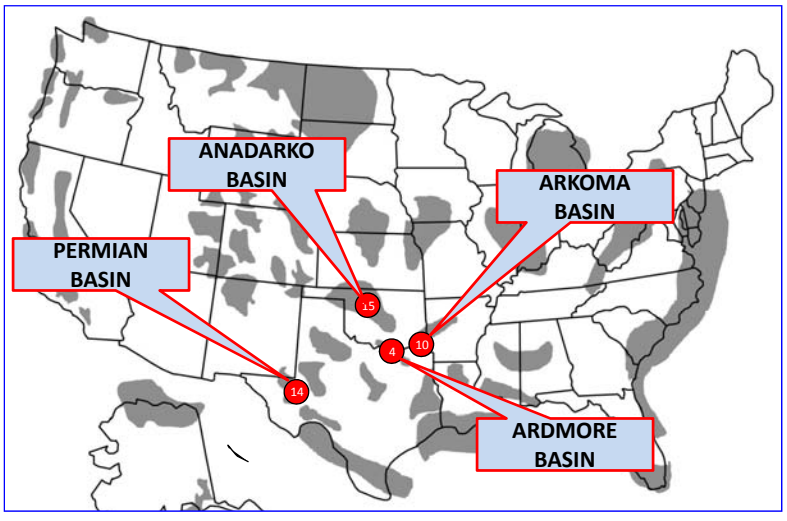
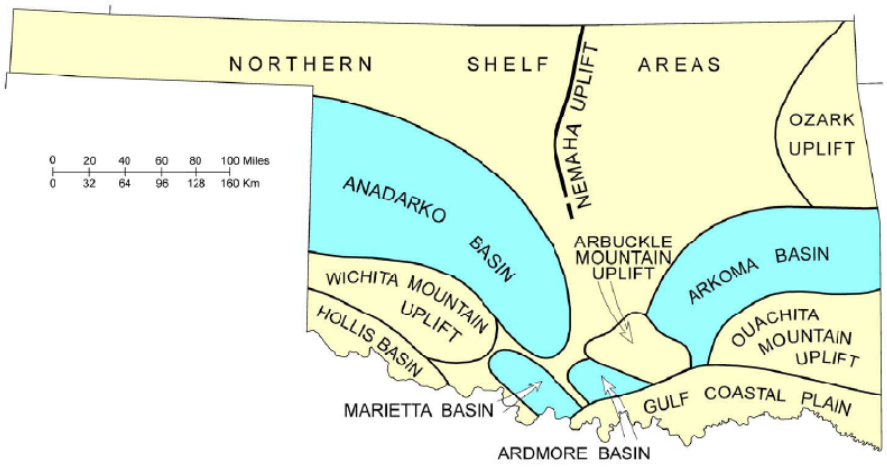
Woodford Shale Plays:

Arkoma, Anadarko, Ardmore, and Permian Basins

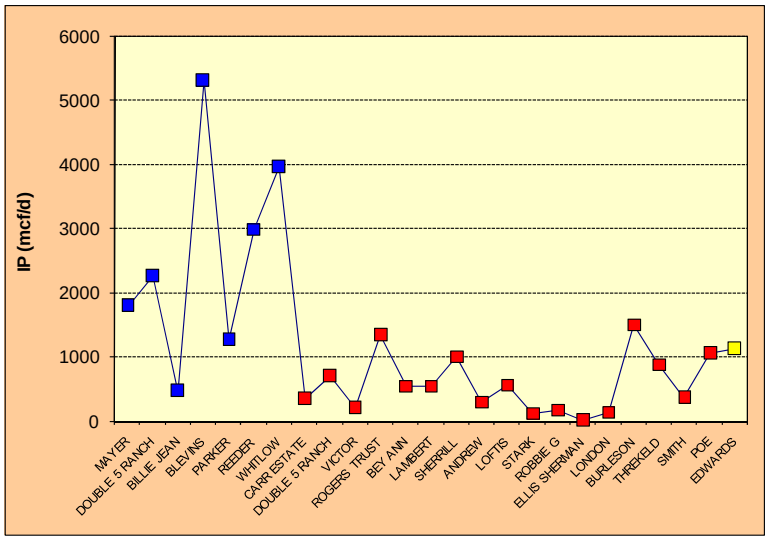


Woodford Shale Basins, Oklahoma

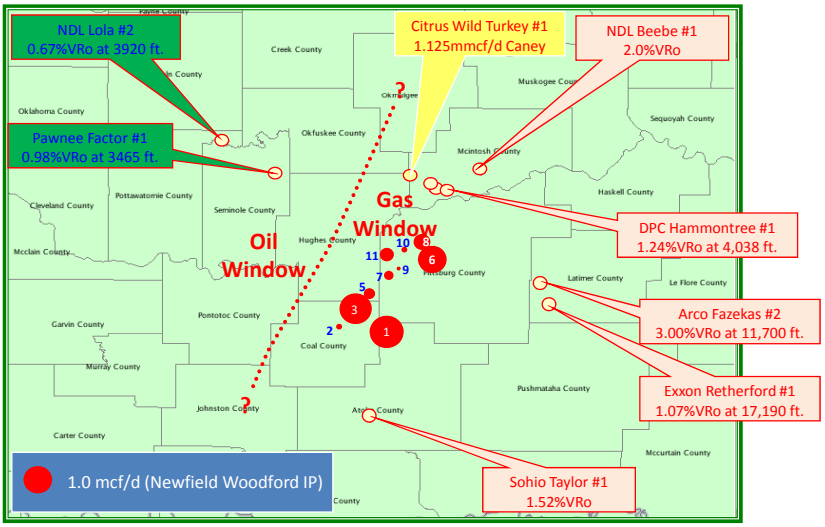


Cardott, 2007

Comparison of early wells in Arkoma Basin: Vertical vs. Horizontal



Select Wells: Arkoma Basin (Oklahoma)



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      - Midland Basin
      - Central Basin Platform
      - Delaware Basin
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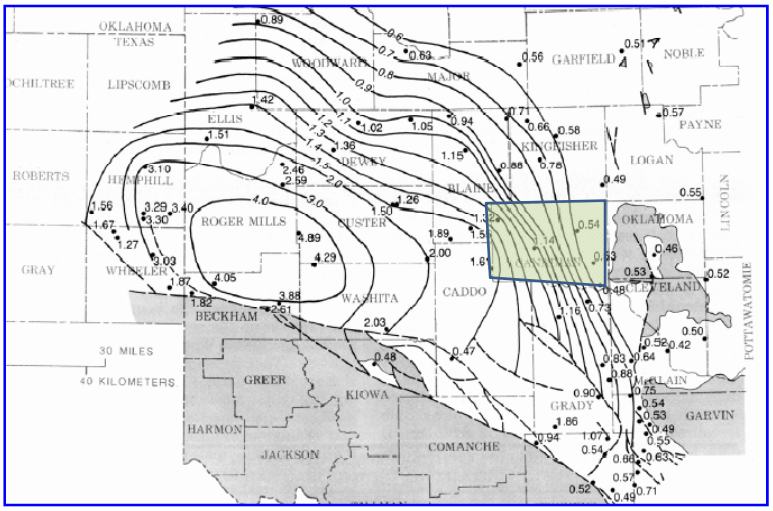
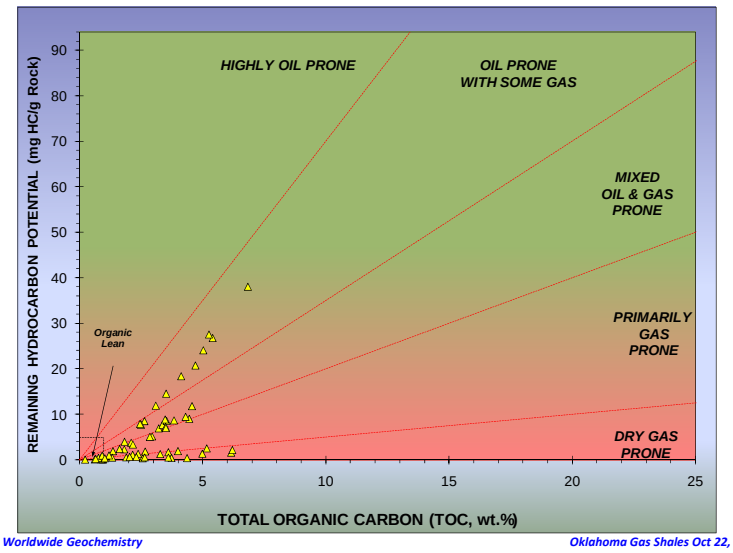
Thermal Maturity, Anadarko Basin: focus on Canadian County area



Cardott, 1989

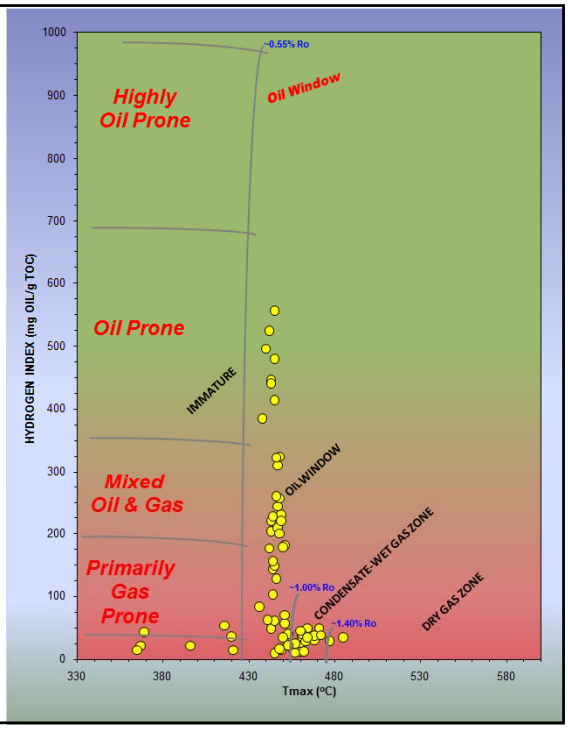
Woodford Shale, Canadian County Anadarko Basin



Anadarko Basin

Canadian County, Woodford Shale:

Extent of conversion and Thermal Maturity



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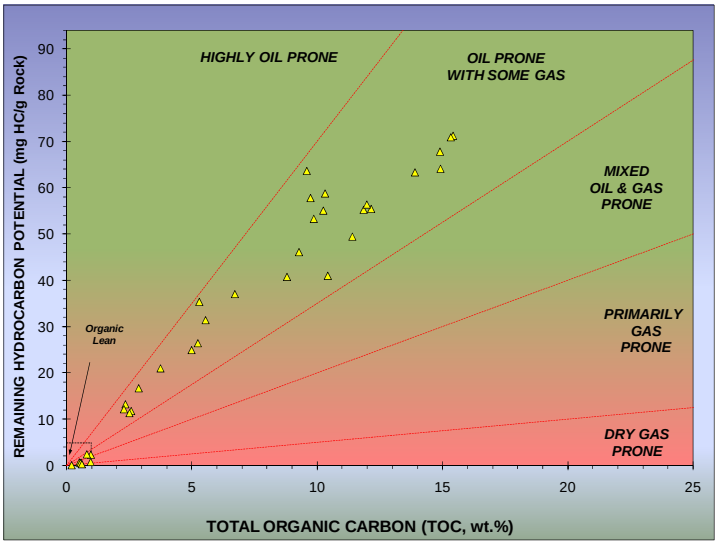
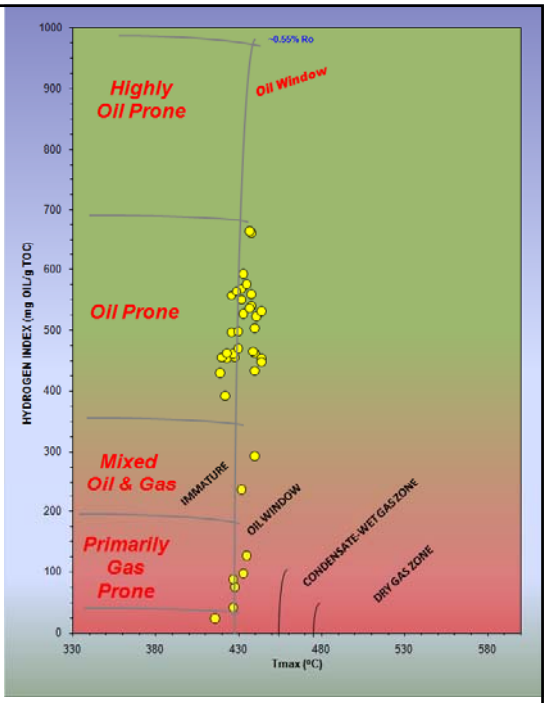
Woodford Shale, Ardmore Basin



Ardmore Basin

Woodford Shale

- **High remaining potential**
- **Low to moderate Thermal maturity**



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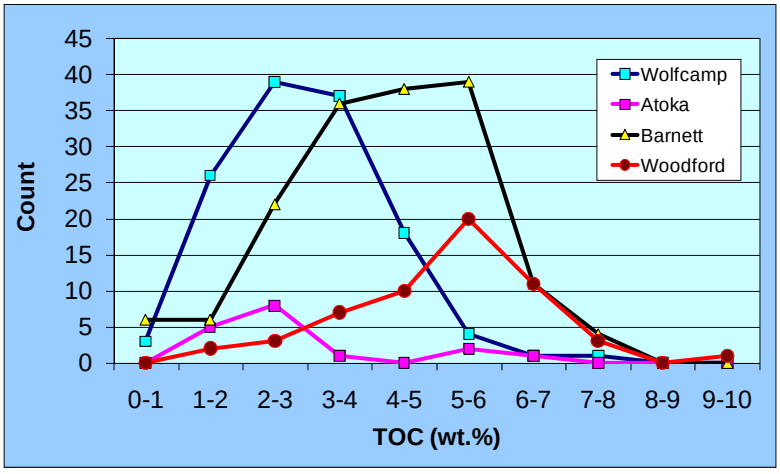
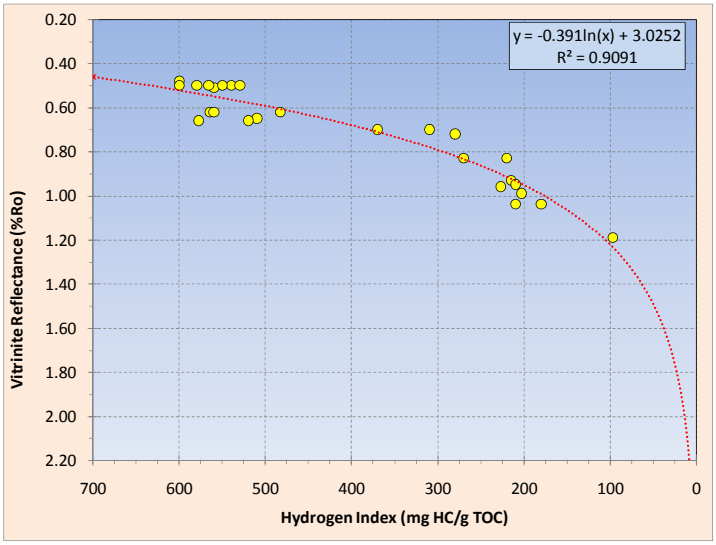
Distribution of TOC in Permian Basin

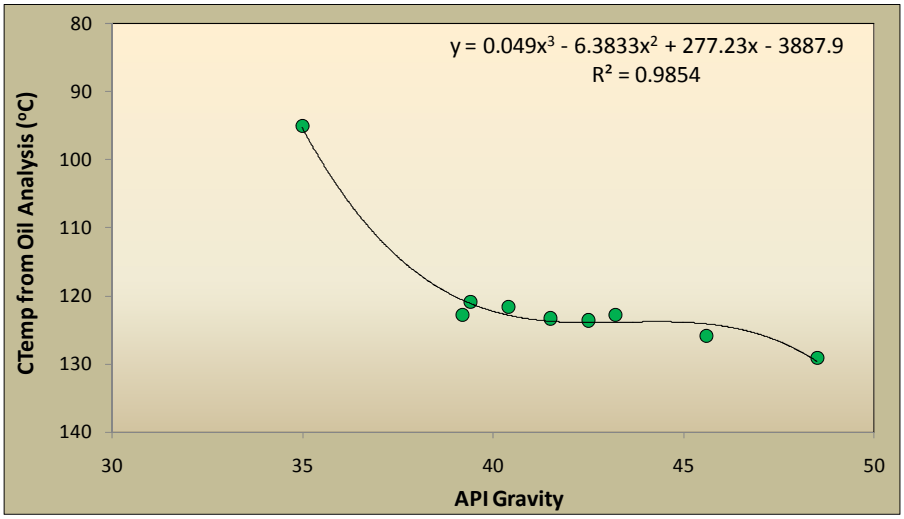


Woodford Shale, Permian Basin:

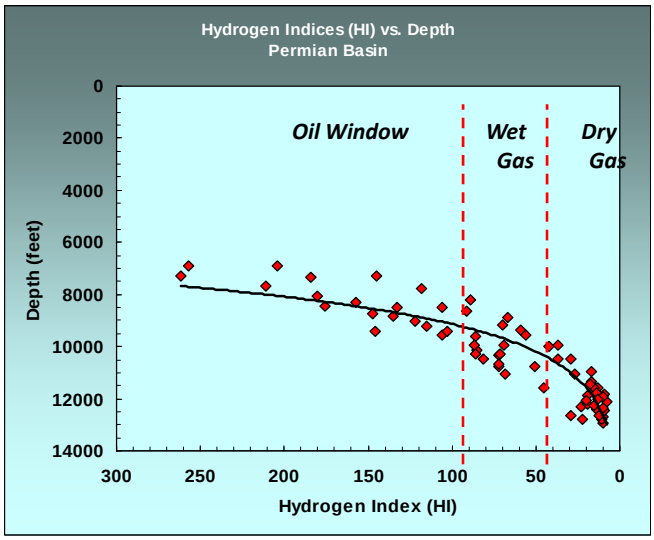
Decrease in Hydrogen Index with increasing thermal maturity



Predicted Temperature of Earliest Generated Woodford Shale Oil



Permian Basin: oil and gas windows



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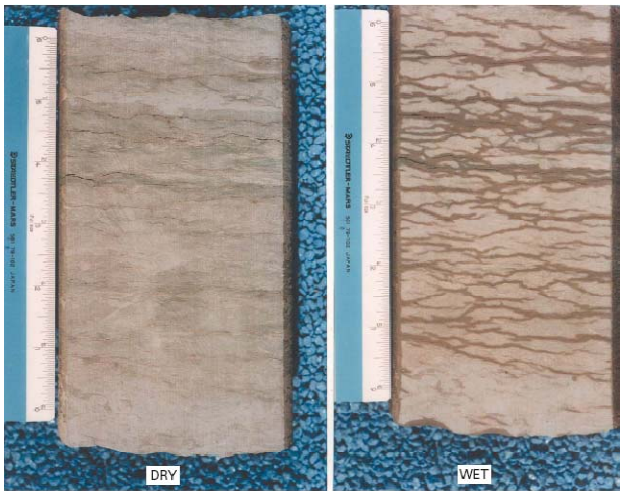
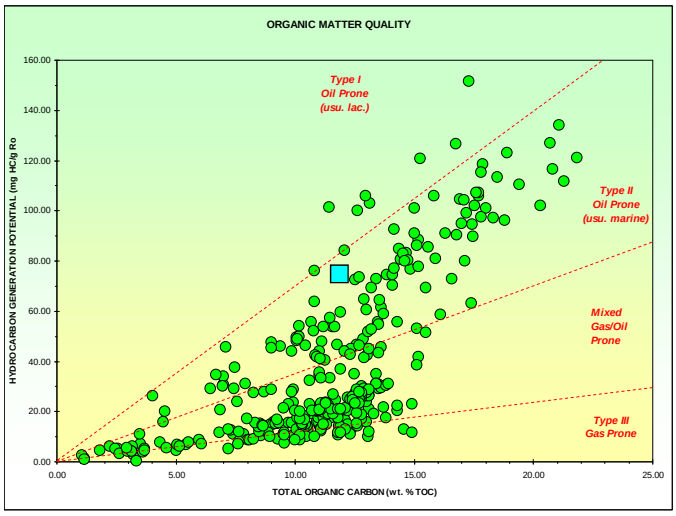
Fractures in Bakken Shale

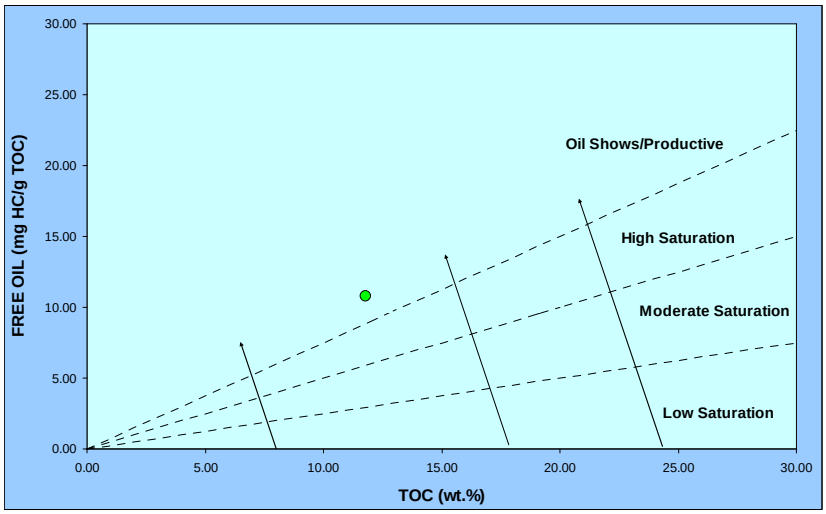


Pitman et al., 2001

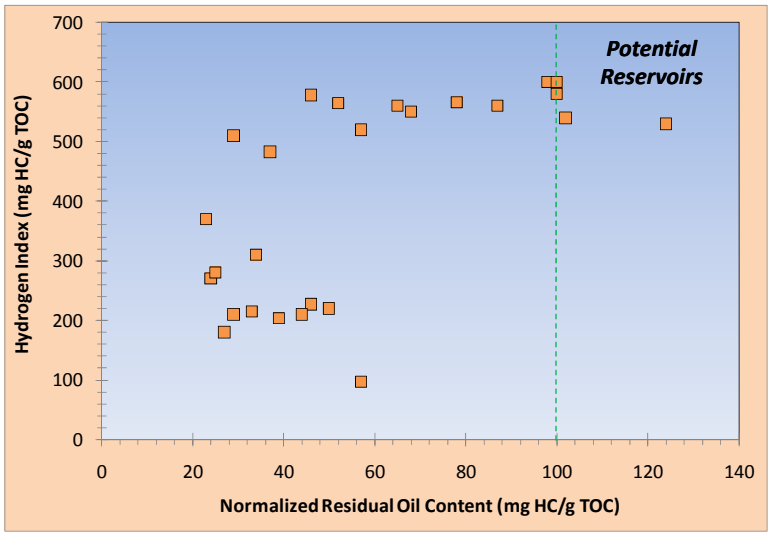
Bakken Shale Database
Williston Basin, USA



Residual Oil Saturation from geochemical analyses



Free Oil Content at Low Level Conversion of Woodford Shale



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Summary

- Woodford Shale geochemistry is variable in terms of
  - Organic richness
  - Original generation potential
  - Thermal maturity
  - And hence... Gas contents, GIP, and EURs
- Make use of all available samples and analytical techniques to optimize exploration and production impact

Thank you !

Peace be with you !

(Shalom)

(Salam Alakum)

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