Conventional and Unconventional Petroleum Systems of the Delaware Basin*

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Abstract

Although one of the major producing basins in the U.S.A., details of Permian Basin petroleum systems have not been published except for the Ordovician (Katz, 1994). The Permian Basin is comprised of the Delaware and Midland basins with the Central Basin Platform juxtaposed between them. A classical petroleum systems study of the entire Permian Basin was originally initiated in 2000 that included thousands of source rock and hundreds of oil samples. This effort was an update on the work of Smith and Jones (1965) and Williams (1977) that Hill et al. (2003) presented. However, this work is further updated focusing on the unconventional systems in the basin. Early efforts to establish unconventional production to produce gas from the Barnett Shale occurred in Reeves County, Texas in the Delaware Basin. However, the shale was less brittle than in the Ft. Worth Basin and was oil window mature in south-central or very deep (ca. 12-15,000 ft) in northern Reeves County. In the southwestern portion of Reeves Co., the Fasken State 36 #1 penetrated and tested the Barnett Shale at just over 7,000 ft. This well did produce minor amounts of gas (ca. 50 mcf/day) and small amounts of condensate (8 bbls/day) for a limited time. Thermal maturity is post-peak to volatile oil window in agreement with canister gas data from this well and carbon isotopic analysis of the Fasken State 34 #1 gas. The 34 #1 well shows oil crossover as indicated by S1/TOC (x100) ratios of over 100 mg oil/g TOC in a 200 ft interval often indicative of potential production, all other factors being suitable for hydraulic stimulation. Petroleum source rocks in the Permian Basin include Ordovician, Devonian, Mississippian, Pennsylvanian, and Permian Wolfcampian, Leonardian and Guadalupian series. Most of these systems are oil prone kerogens. While these systems are primarily siliciclastic shales, the Bone Springs is a carbonate to marly shale source rock. Maturation-wise there are distinct thermal histories that show different relationships to depth particularly in the Delaware Basin. This paper focuses on Delaware Basin petroleum systems and on characterization and quantification of resources for unconventional production. The amounts of petroleum generated, expelled, and retained in situ for each source rock are calculated. The goals are volumetric calculations and prediction of reservoir properties from these analyses including the impact of alteration processes such as gas exsolution.

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Albert Maende, Wildcat Technologies

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- Geomark Research
- David Martineau, Dallas Production
- Co-authors

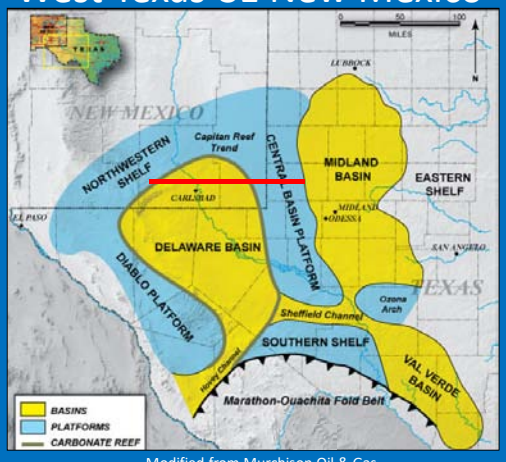
Outline of Presentation

- Historical Perspective
  - Recent
  - Past
- Thermal maturity
- Source rocks
  - Present-day
  - Restored
- Caveats of select analysis
- Synopsis

Permian Basin Location Map and Cross Section

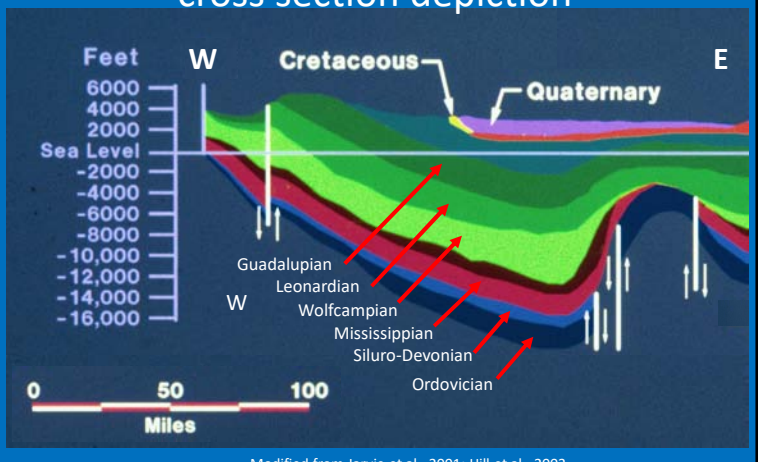
across Central Basin Platform to western Delaware Basin

Permian Basin
West Texas-SE New Mexico

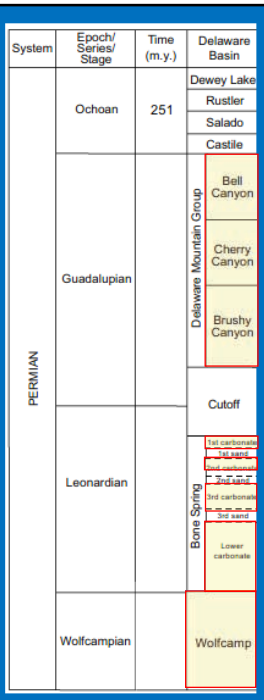


Modified from Murchison Oil & Gas

Delaware Basin to Central Basin Platform cross section depiction



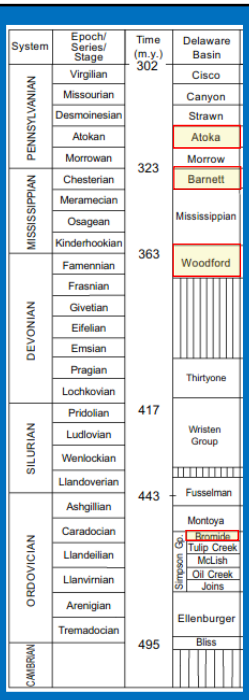
Modified from Jarvie et al., 2001; Hill et al., 2003



Our Mudstoned Friends: the Source Rocks

- Ordovician Simpson/Bromide
- U. Devonian Woodford
- U. Mississippian Barnett
- Pennsylvanian Atoka

- Permian Wolfcamp
- Permian Leonard (Bone Spring)
- Permian Guadalupian
  - Delaware Mountain Group
    - Brushy Canyon
    - Cherry Canyon
    - Bell Canyon



Delaware Basin Petroleum Systems Assessment

1.Ordovician Simpson-Sourced Oils
2.Upper Devonian Woodford-Sourced Oils
3.Mississippian Barnett-Sourced Oils
4.Upper Pennsylvanian Cline-Sourced Oils
5.Lower Permian Wolfcamp-Sourced Oils
6.Transitional WC/BS Facies Oils
7.Leonardian Bone Spring etc.-Sourced Oils
8.Guadalupian Carbonate-Sourced Oils

Curtis and Zumberge, 2017

Permian Basin Petroleum Systems

(Jarvie et al., 2001; Hill et al., 2003)

	Source	Principal Reservoirs
I	Simpson	Ellenburger
II-A	Woodford	Silurian, Devonian
II-B	Woodford	Silurian, Devonian
III	Penn. (+Miss.?)	Pennsylvanian
IV	Wolfcamp (L.L.)	Wolfcamp, Dean, Spraberry
V	U. Leonard (Midland)	San Andres
VI	L. Leonard (Midland)	Clearfork
VII	Leonard (DMG)	San Andres
VIII	L. Leon. (DMG)	Pennsylvanian, Wolfcamp, Abo
IX	Guadalupe (DMG)	Queen

Historical Permian Basin Petroleum Systems Assessments

Jones and Smith (1965)

- Type I — low S, lowest N
- Type II — mod. S, low N
- Type III — highest S, mod. N
- Type IV — low S, high N
- Type V — high S, high N

These results reflect differences in source rock type and composition.

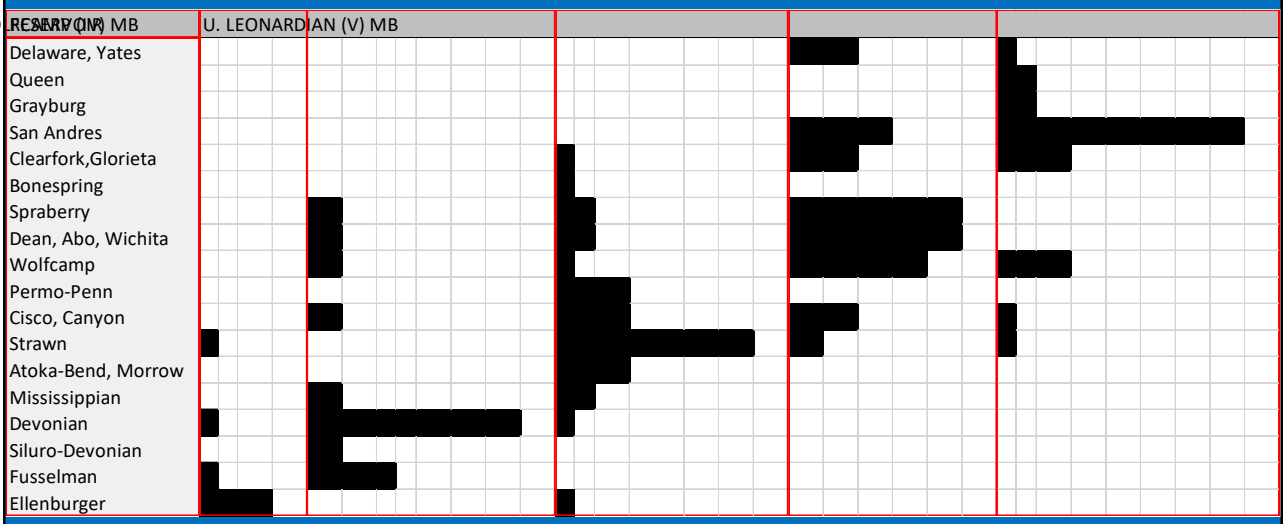
Permian Basin Petroleum Systems Assessment
Jack A. Williams, 1977

Type	Source	Principal Reservoirs
I	Simpson	Ellenberger
II-A	Woodford	Silurian-Devonian
II-B	Woodford	Silurian-Devonian
III	Pennsylvanian (+Miss.?)	Pennsylvanian
IV	Wolfcamp + L. Leonardian (Midland)	Wolfcamp, Dean, Spraberry
V	U. Leonardian (Midland)	San Andres
VI	L. Leonardian (Midland)	Clearfork
VII	Leonard (Delaware)	San Andres
VIII	L. Leonardian (Delaware)	Penn, Wolfcamp, Abo
IX	Guadalupian (Delaware)	Queen

504 oils
468 classified as 'pure' oil types

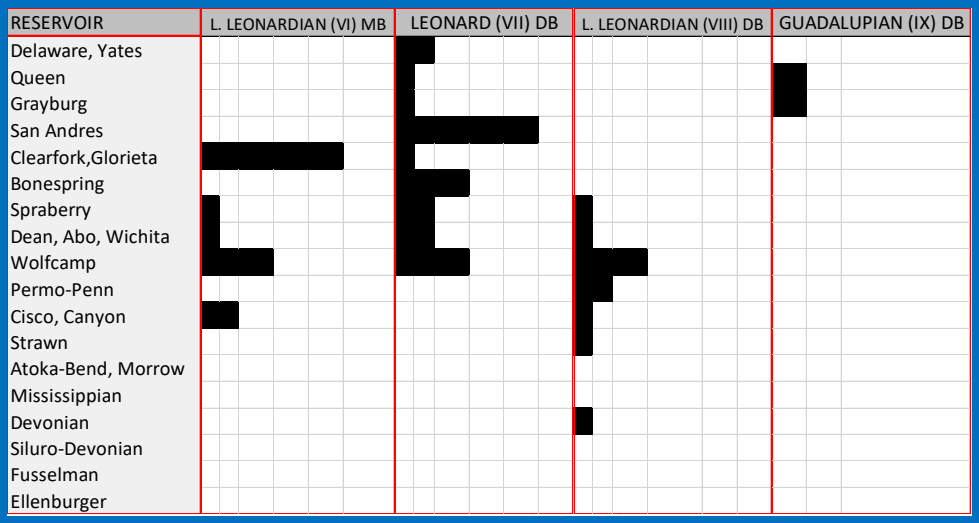
Analytical
- Whole oil carbon isotopes
- Oil fraction carbon isotopes
- C4-C7 light hydrocarbons
- C15+ hydrocarbons
- Optical rotation
- Infrared spectrum

Williams Source to Reservoir Correlations: Type I-V oils



Williams, 1977

Williams Source to Reservoir Correlations: Type VI-IX oils

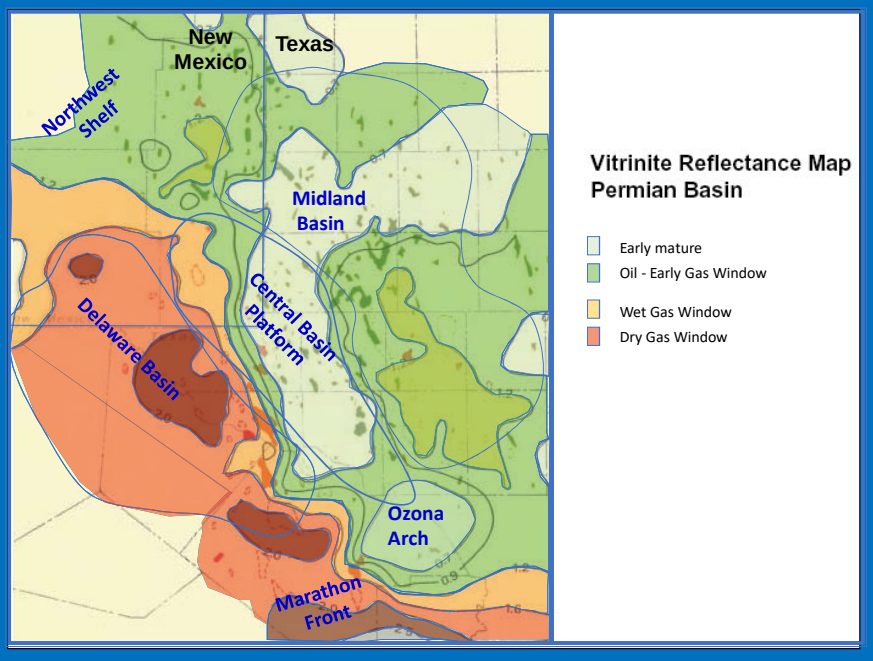


Williams, 1977

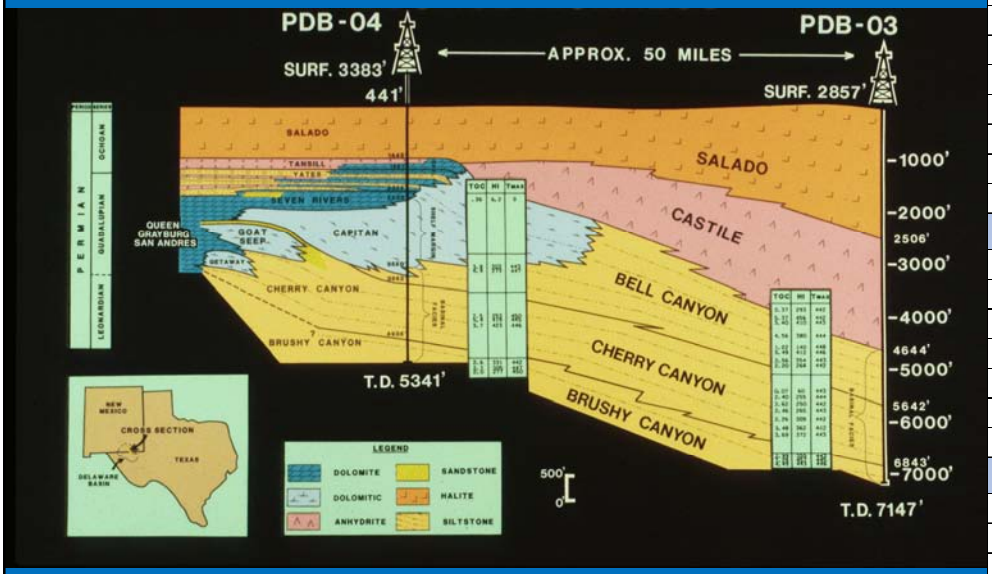
Permian Basin Devonian Maturity Map

Rule of Thumb:
-1,000 ft ~ -0.10%Ro

Courtesy Amoco



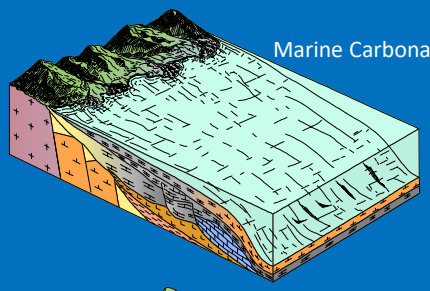
U. Guadalupian Cross Section, Eddy Co., NM with TOC, HI, and Tmax

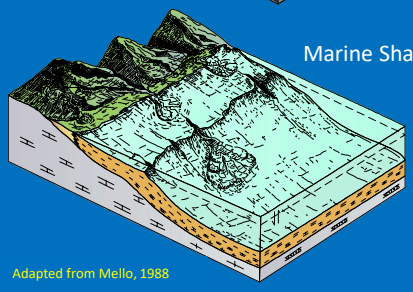


Courtesy Jack D. Burgess

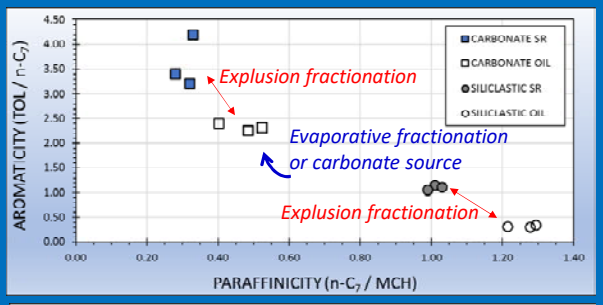
TOC	HI	Tmax	%Roe
BELL CANYON			
2.37	293	442	0.80
5.37	456	442	0.80
3.40	410	443	0.81
4.56	380	444	0.83
1.22	140	448	0.90
5.49	412	446	0.87
2.56	354	443	0.81
2.20	268	442	0.80
CHERRY CANYON			
0.07	60	443	0.81
2.40	255	444	0.83
2.62	250	442	0.80
2.46	265	443	0.81
2.26	309	442	0.80
3.48	362	442	0.80
3.69	372	443	0.81
BRUSHY CANYON			
2.99	355	443	0.81
7.29	457	445	0.85
4.49	443	446	0.87

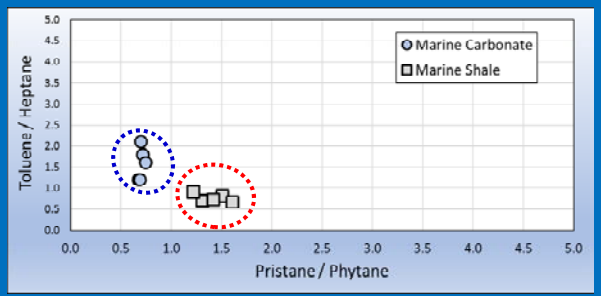
Source Rock Depositional Setting - Marine Carbonate and Marine Shale:
Evaporative and Expulsion fractionation versus Carbonate Source Rocks/Oils



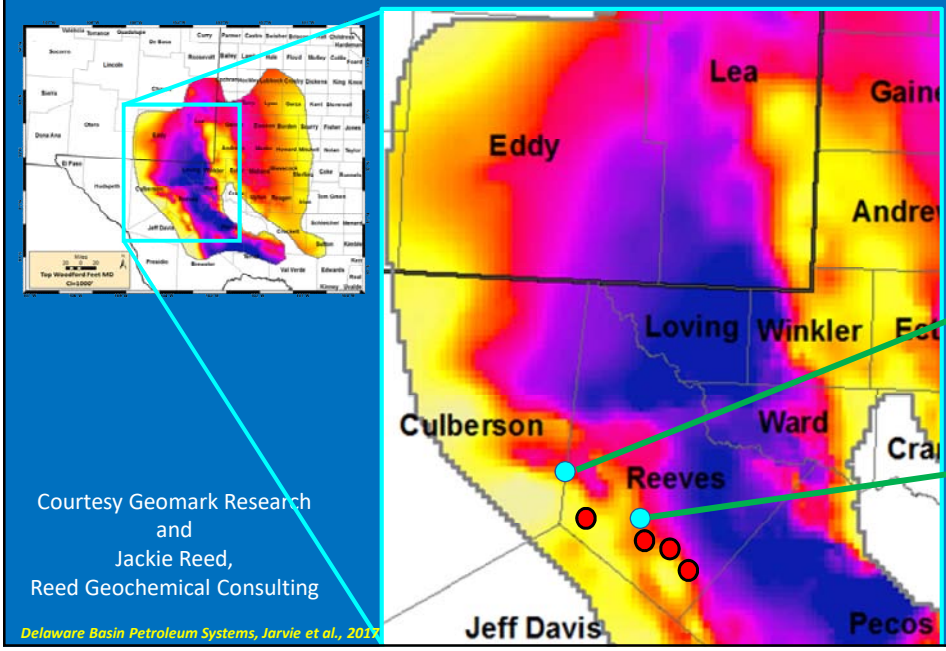


Adapted from Mello, 1988





Depth Contour Top of Woodford, Delaware Basin



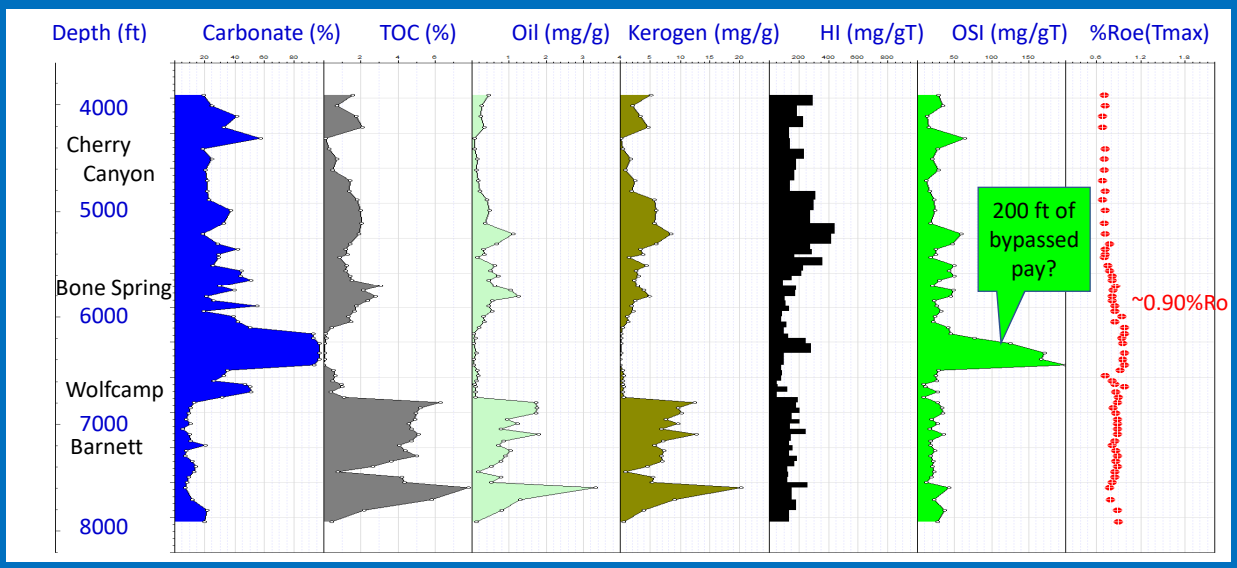
Courtesy Geomark Research
and
Jackie Reed,
Reed Geochemical Consulting

Pure Oil Resources, 2001
Tested the Barnett Shale
Flow 757 mcf/d from
13,595 to 13,620 ft

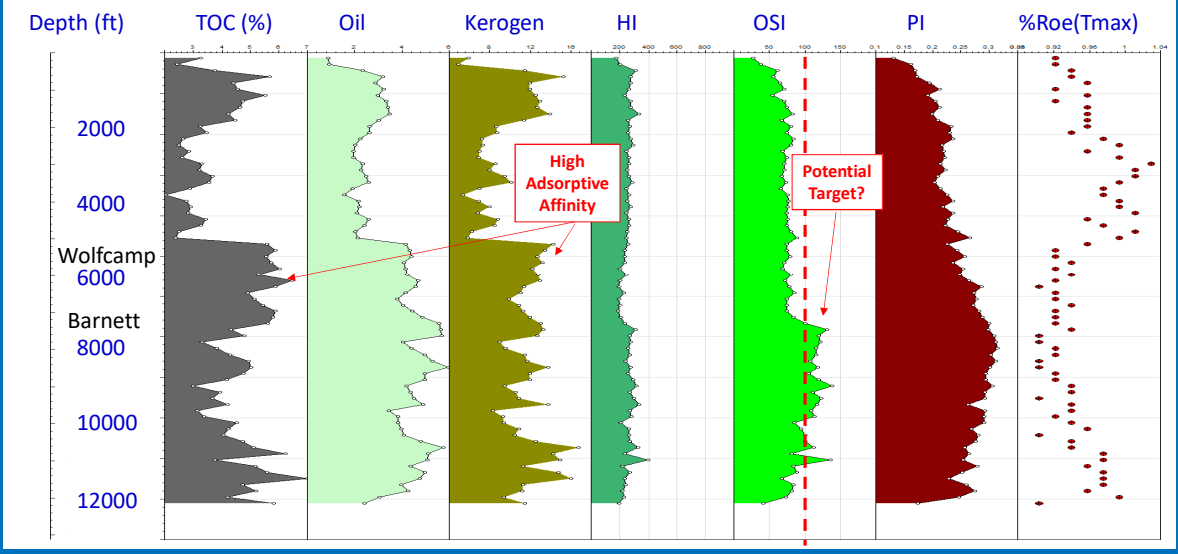
Dallas Production, 2003
Barnett Shale
7100-7800 ft
Fasken 36-1, Fasken 34

Apache Alpine High wells

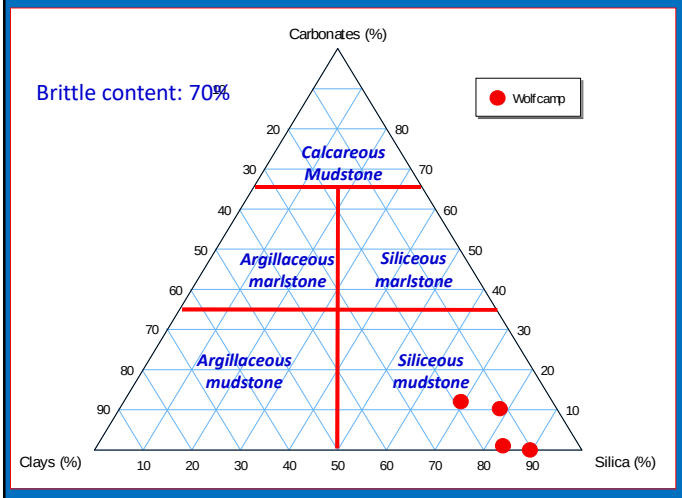
Fasken 34, Reeves County, Texas

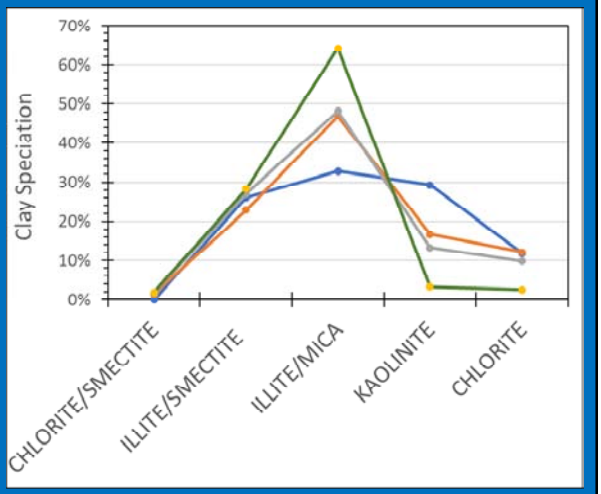


Geochemical Logs of Fasken State 36-1t



Mineralogy and Clay Speciation of select Wolfcamp samples at Fasken Ranch 36-1

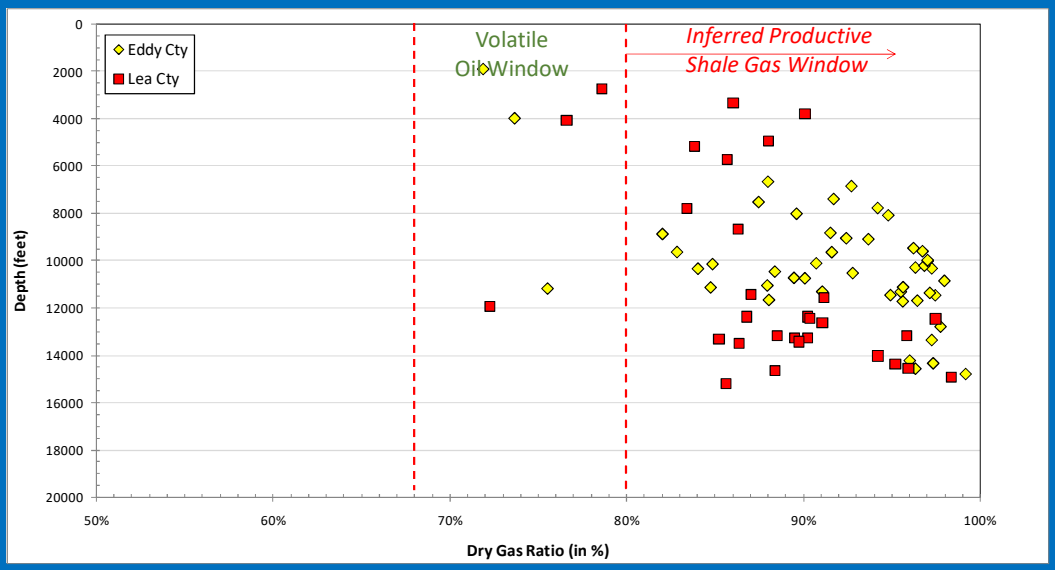




Modified from Allix et al. (2010)

Southeastern New Mexico Gas Data:

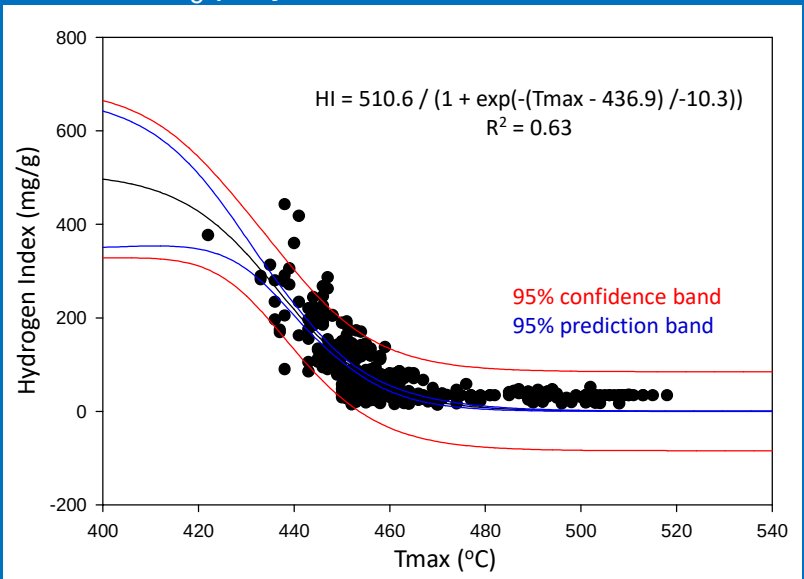
Eddy and Lea Counties – Penn. and Permian Conventional Reservoirs



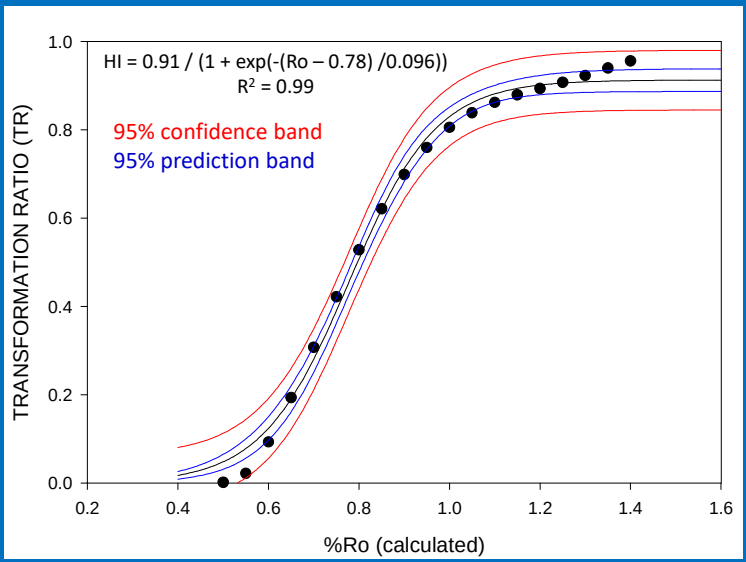
Jarvie, 2003

Sigmoidal Fit of Wolfcamp HIpd and Tmax Data:

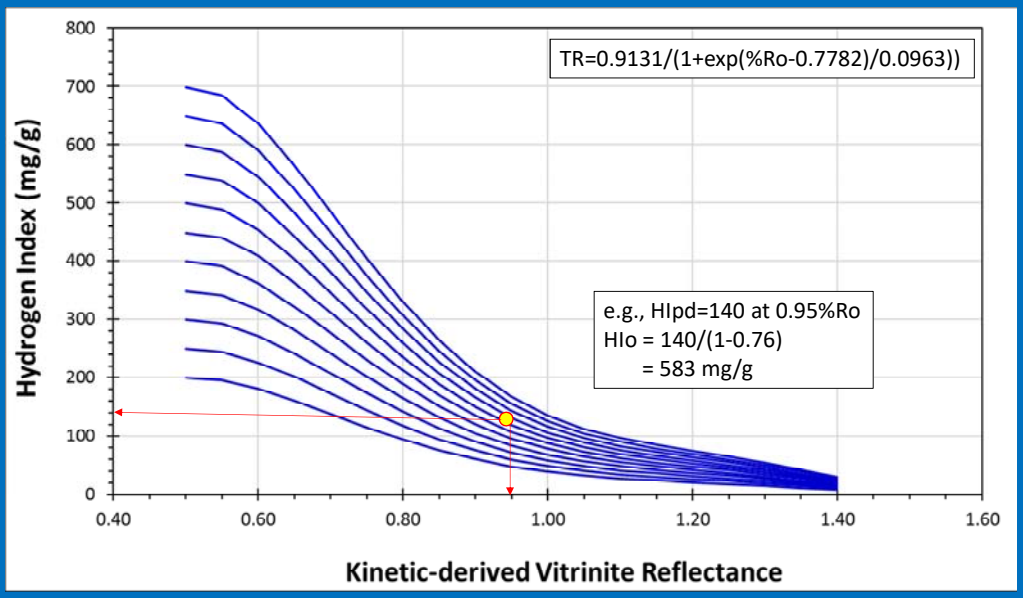
HI_o projected at 430°C Tmax



Sigmoidal Fit of Wolfcamp Transformation Ratio to Tmax Data:

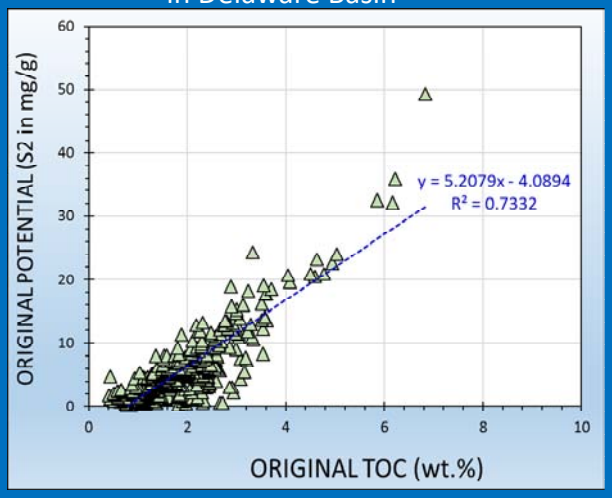


Estimation of Original Hydrogen Index from %Ro or Equivalents

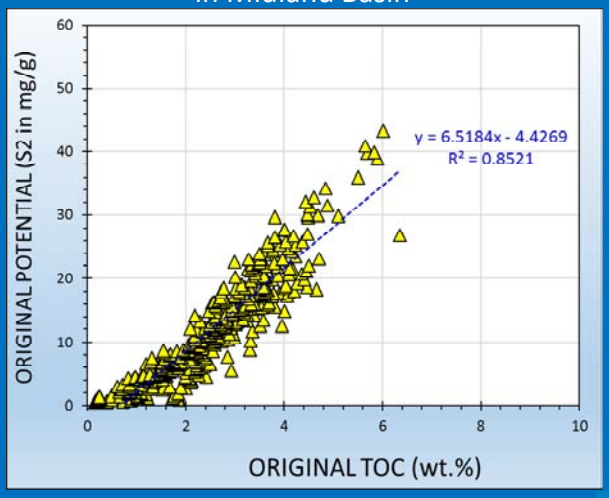


Comparison of Restored Wolfcamp Data in Delaware and Midland Basins

Restored Wolfcamp in Delaware Basin



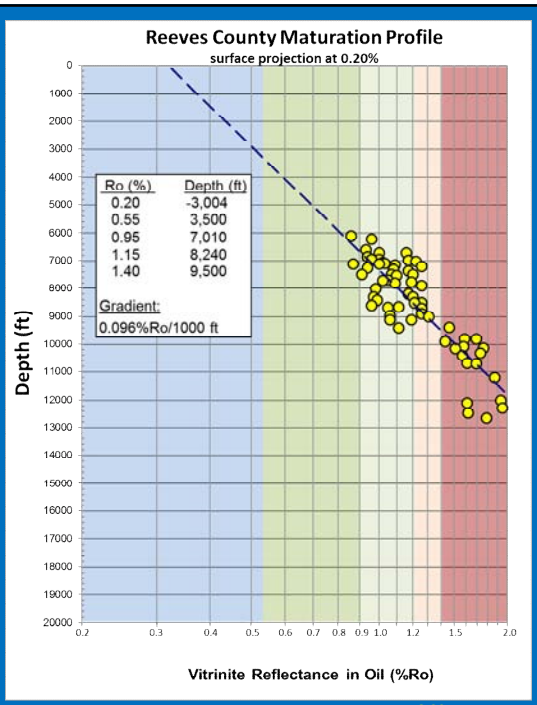
Restored Wolfcamp in Midland Basin

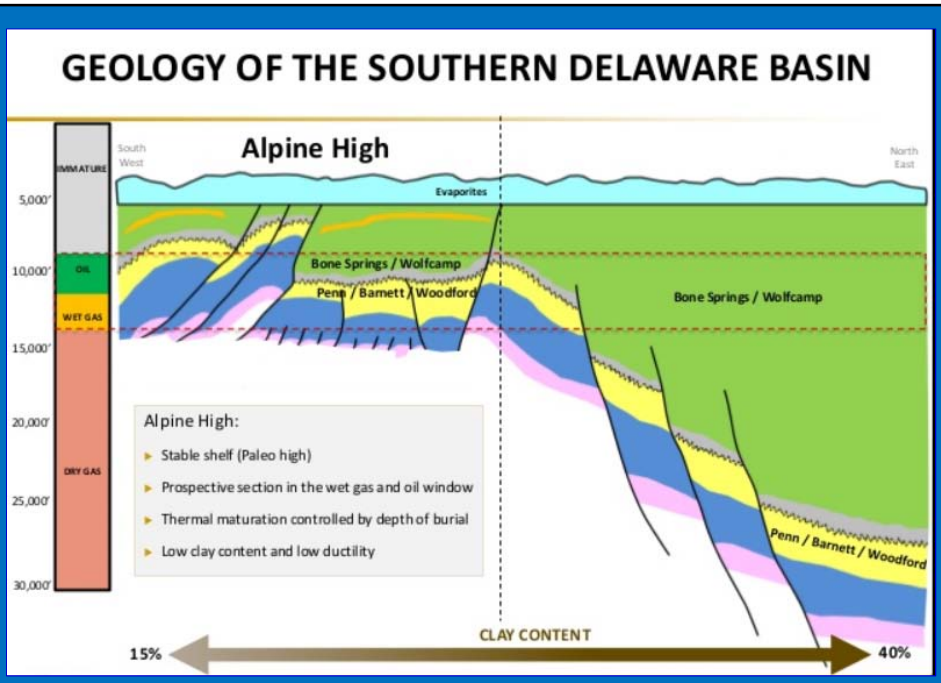


Thermal Maturity Data in southcentral Reeves Co.:

Volatile Oil Window to Dry Gas Window Generally related to present-day depth

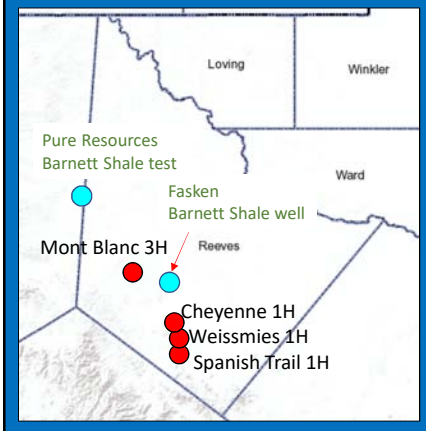
There are notable exceptions



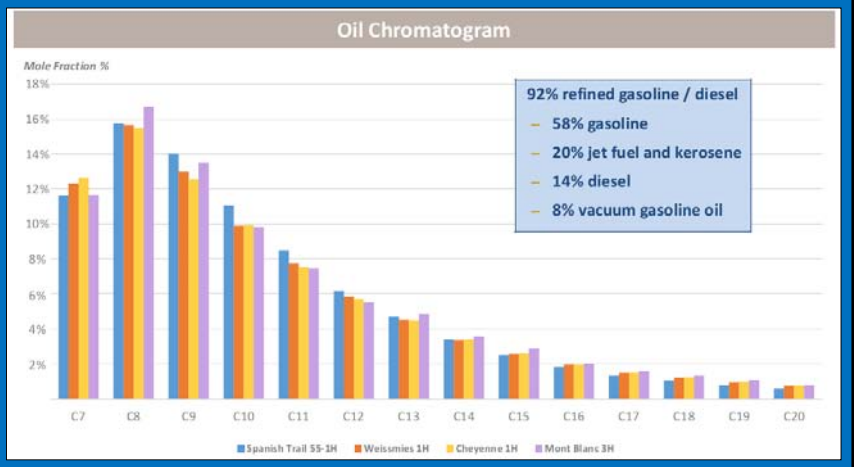


Christmann, 2016 (Apache Barclays presentation)

Alpine High Barnett and Woodford (3) Wells

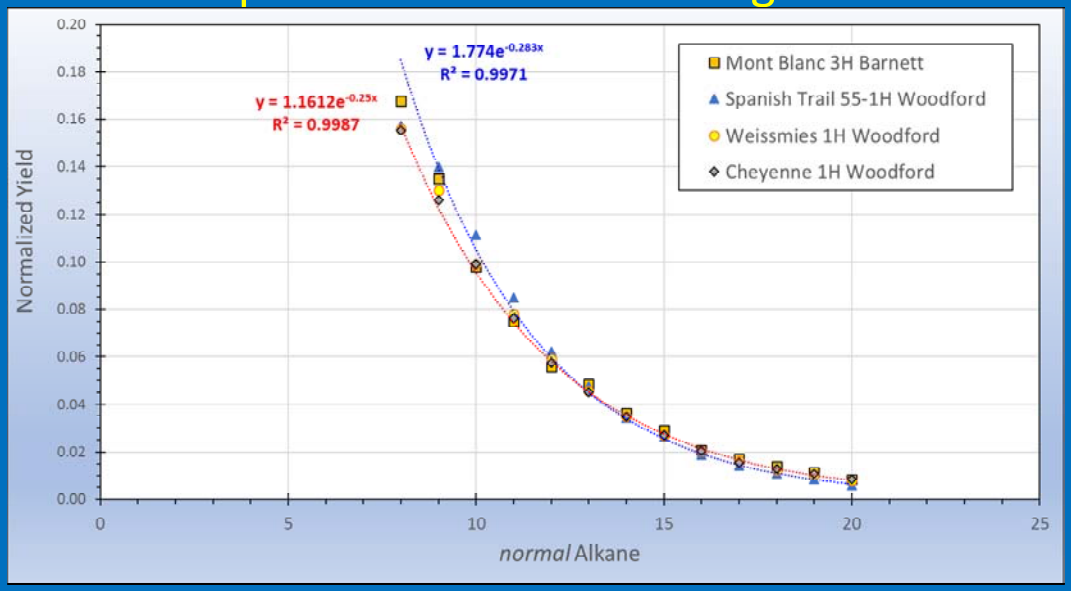


Apache Mont Blanc 3H: 22,441 24-hr IP GOR
Apache Cheyenne 1H: 28,709 24-hr IP GOR
Apache Weissmies 1H: 25,345 24-hr IP GOR
Apache Spanish Trail 1H: 60,037 24-hr IP GOR



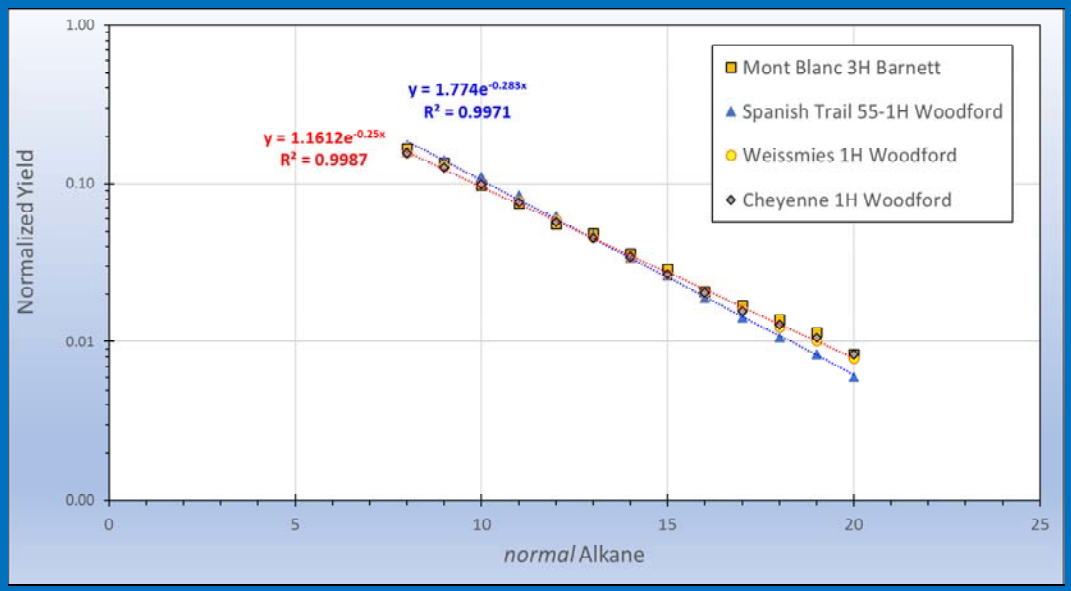
Christmann, 2016 (Apache Barclays presentation)

Analysis of GC Histograms from Alpine High: exponential fit of GC histograms

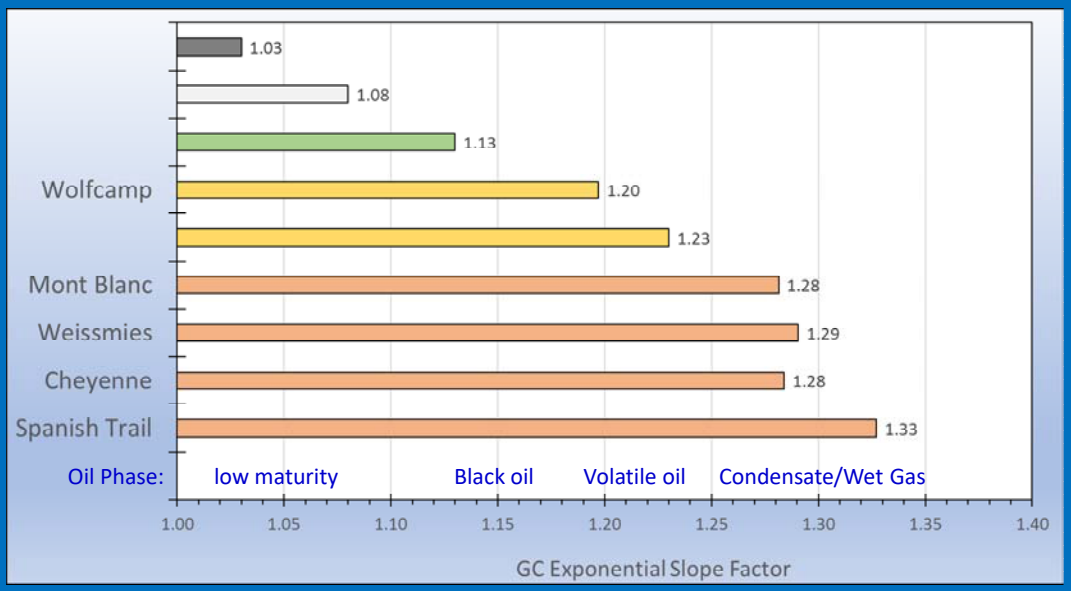


Analysis of GC Histograms from Alpine High:

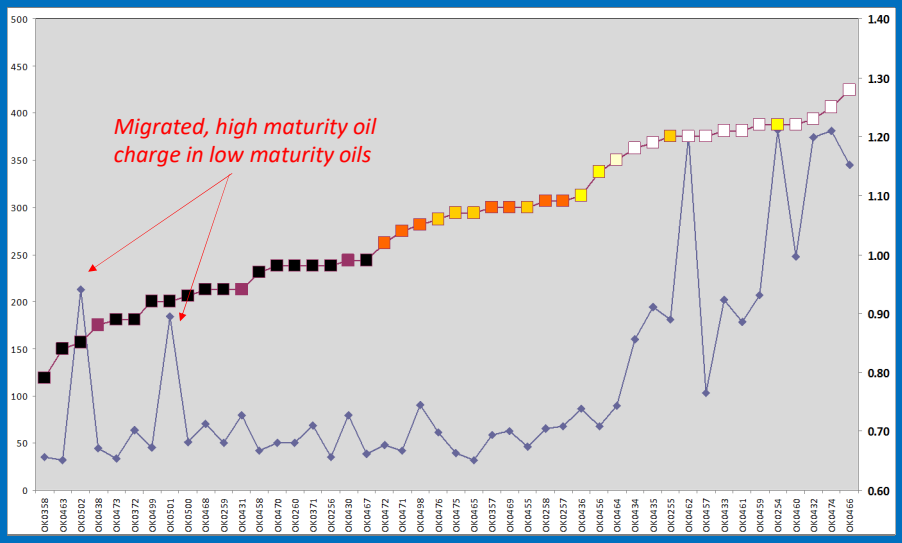
logarithmic fit of GC histograms showing slight slope differences; Spanish Trail slight higher maturity



Assessment of Oil Type/Phase: Wolfcamp from central Reeves County, Texas

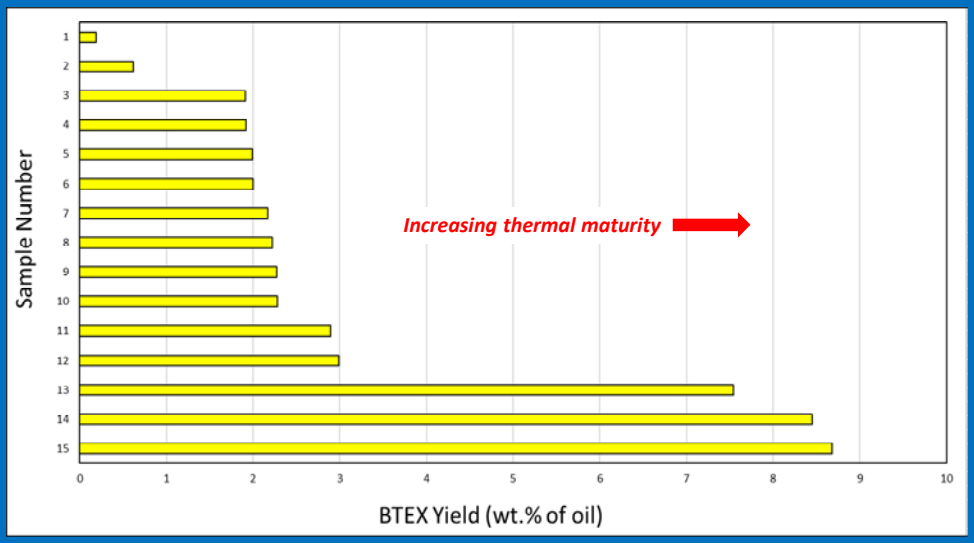


High Diamondoid Content in Oil Window Maturity Oils
indicative of secondary, high maturity oil charge



Rocher et al., 2015

Increasing Yield of BTEX Compounds are indicative of increasing thermal maturity

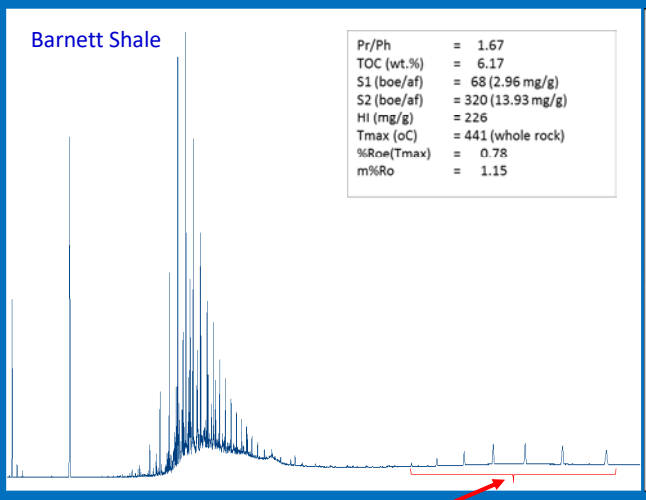


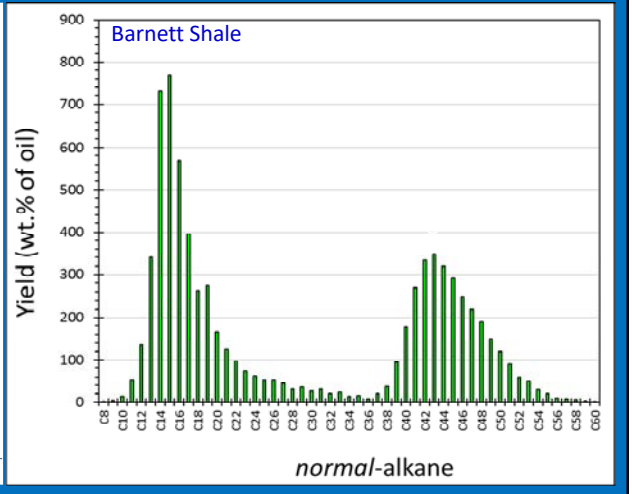
BTEX =

- Benzene
- Toluene
- Ethyl benzene
- Xylenes (3)

Some Shales yield High Molecular Weight Waxes:

these will both occlude pore throats as well as precipitating in well bore



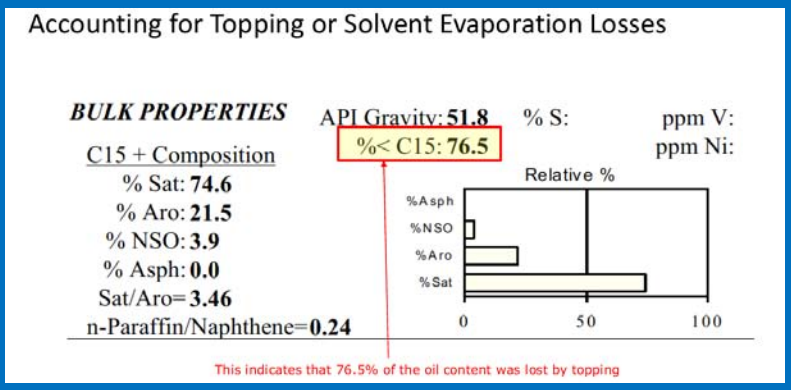


Peak heights can be very deceptive; peak areas or wt.% of oil must be used as shown in the GC histogram on right

Assessing Mobile Oil Content

understanding SARA data especially as related to mobile oil

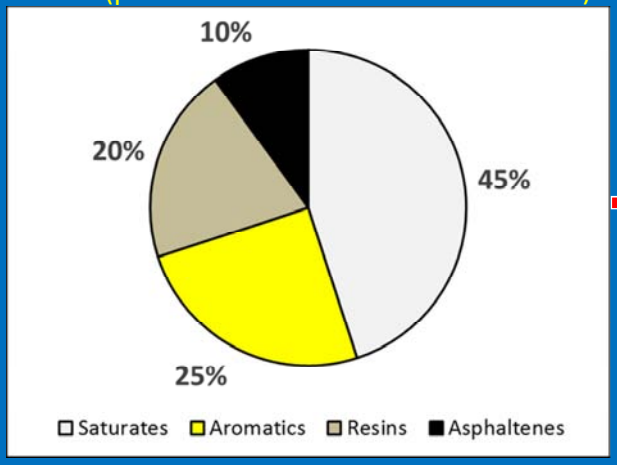
Evaporative loss in extracted and oils is reported as %<C15, i.e., C_1-C14+ all of which are saturates and aromatics



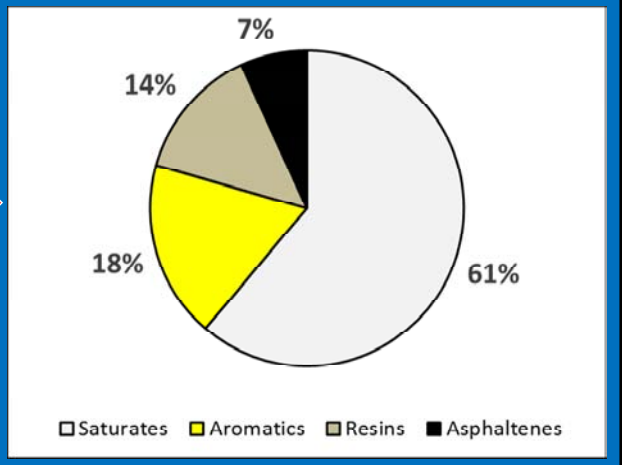
Restoring Full SARA Composition:

losses during topping/evaporation are 90% saturates and 10% aromatics

SARA (produced oil or solvent extracted oil)



Restored SARA



Synopsis

- Petroleum Systems in the Delaware Basin are simple by source rocks but complicated by individual conventional reservoirs and unconventional targets
- Southwestern Reeves County is characterized by
  - Condensate-wet gas in the Mississippian-Devonian
  - Black to volatile oil in the Permian
- Restored petroleum generation potentials show the high performance for retaining and expelling petroleum
- Aromaticity and SARA vary with source rock type, thermal maturity, and whether restored or 'as is'

Thank you.

Comments or Questions?

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