

Oil and Shale Gas from Barnett Shale, Ft. Worth Basin, Texas*

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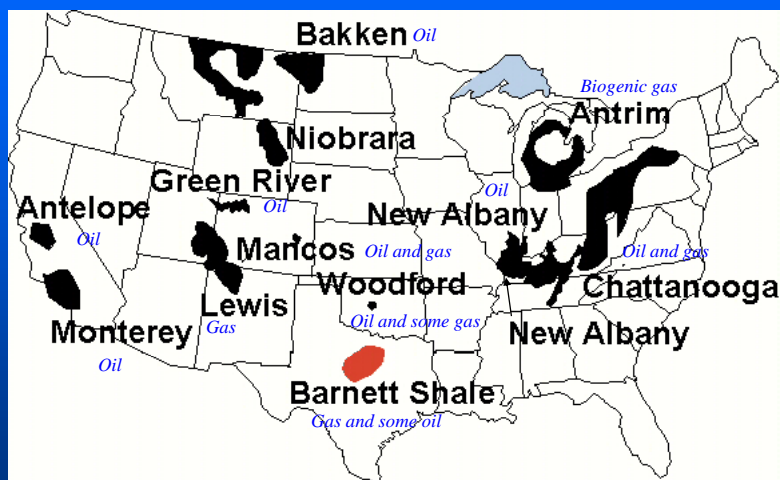


Fractured Shale Petroleum Systems

- *Effective Source and Reservoir Rock*; other reservoirs fed by episodic expulsion
- Fractured shale reservoir is chemically (hydrocarbon generation) and physically (tectonically) controlled
- **High hydrocarbon potential and episodic seal mean other horizons contain hydrocarbons**



Fractured shales yield oil and gas in various basins:
there exist numerous similarities and differences among these systems



Ref: USGS

Fractured shale source-reservoir systems



USGS Data on Gas Bearing Shales

Basin	Formation	T.O.C. (wt.%)	Range of Maturities (%Ro)	Estimated Recoverable Shale Gas (Tcf)	Shale Gas in place (Tcf)
Appalachian	Ohio Shale	1-4.5*	0.4 - 1.3%	14.5 - 27.5	225 - 248
Michigan	Antrim Shale	1-20	0.4 - 0.6	11 - 19	35 - 76
Illinois	New Albany Shale	1-25	0.4 - 1.0	1.9 - 19.2	86 - 160
Ft. Worth	Barnett Shale	1-12* Ave. 4.5	0.6 - 1.6*	3.4 - 10	54 - 202**
San Juan	Lewis Shale	1-2.5*	1.6 - 1.9	na	na

* modified from USGS ** author's estimate of total gas potential

Ft. Worth Basin

Location and principal geological features delimiting the basin



**Barnett Shale
 is Mississippian-age
 black shale**

It sources oil
 internally and in older
 (Ellenburger)
 and many younger
 horizons

It sources gas from
 primary generation
 and secondary cracking
 of oil

Generalized Stratigraphic Column						
System	Series	Group	Formation	This Report		
Orcadian	Lower	Fredericksburg		Fredericksburg (undivided)		
		Comanche	Trinity	Edwards		
Pennsylvanian	Upper	Cisco	Thrifty Graham	Trinity (undivided)		
		Canyon	Caddo Creek	Colony Creek Shale	Middle Pennsylvanian Unconformity Clastic Facies	
	Brad		Ranger Limestone			
	Graford		Wichell			
	Middle	Whitt	Palo Pinto			
		Strawn	Lone Camp Millsap Lake	Norris Sandstone Lazy Bend		
	Lower	Atoka	Kickapoo Creek	Caddo 1 Rayville		
			Morrow	Atoka II Atoka Big Saline Natum Marble Falls	Big Saline Marble Falls	
		Chester	Osage	Comyn	Comyn	
				Barnett	Barnett	
Chappel		Chappel				
Cambrian	Upper	Starks Vicks				
	Lower	Ellenburger	Honeycut			
	Upper	Wilberns		Cambrian		
				Precambrian		

Per well reserves best of
 all shale gas plays (Reeves, 2000)

Barnett Shale Rock Characteristics

- Organic-rich, black shales
- Thickness up to 1000 ft., average 300 ft.
- Variable lithologic features
 - calcareous shale predominates
 - clay-rich shale intervals
 - cherty intervals
 - dolomitic intervals
- Microfractures present, but limited visible fractures evident at surface

What does it take for an oil or gas discovery in the Barnett Shale?

- Effective source rock
- Migration pathway (fracturing)
- Trap
- Seal(s)
- Overburden rocks
- Complementary timing of events
- Preservation (oil), partial destruction (gas)



General Observations

- High TOC marine shales are more efficient expellers of hydrocarbons
 - 1% poor 3% fair 10% excellent
- High TOC and clay content aid retention of hydrocarbons by adsorption
- Pressure cookers: Generate-form vapor lock - Vent; repeat depending on burial history
- Deeply buried in past, recent uplift, resulting in pressure and temperature drop; 2 phase system

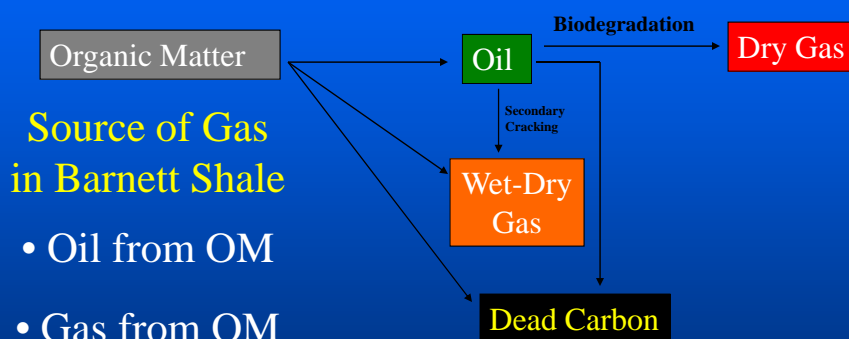


Factors Affecting Petroleum System Efficiency

- Hydrocarbon charge factor
 - source type (oil/gas, kinetic type)
 - source volume
 - source maturity
- Migration - Drainage style
 - lateral
 - vertical
- Entrapment style
 - High impedance (good seals)
 - Low impedance (poor seals)



Generation of Oil and Gas

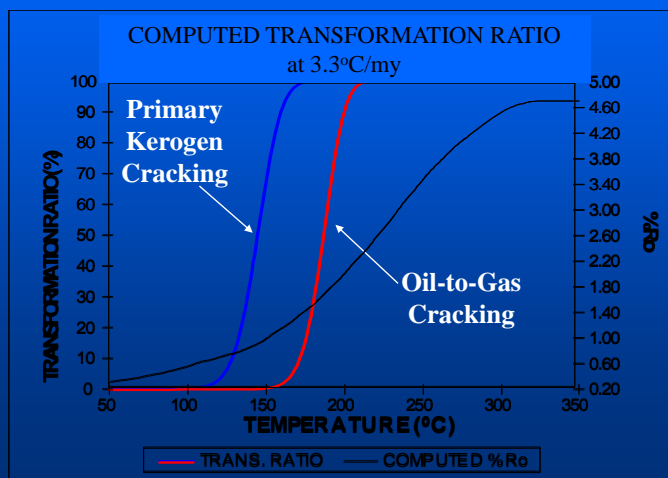


Source of Gas
in Barnett Shale

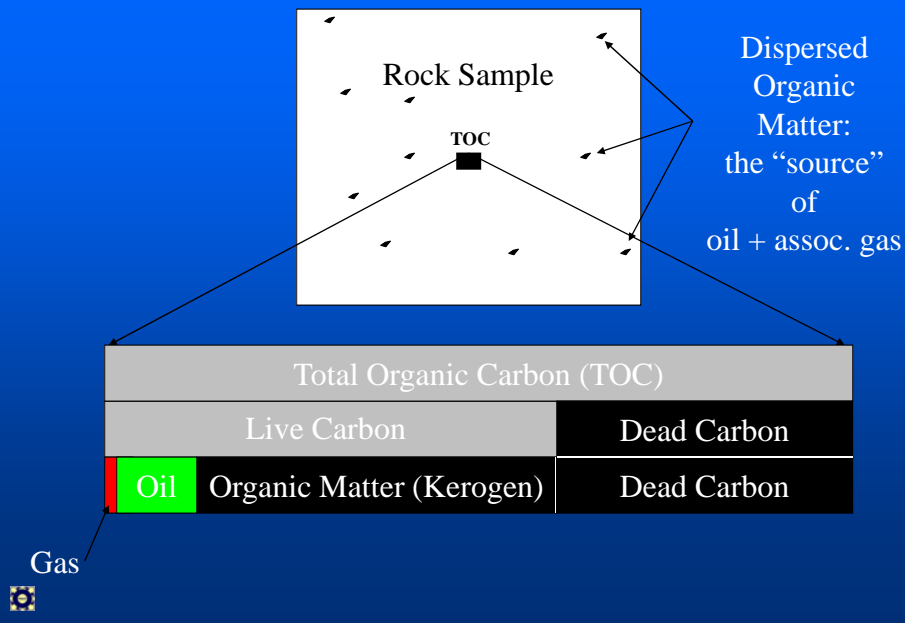
- Oil from OM
- Gas from OM
and
Oil Cracking



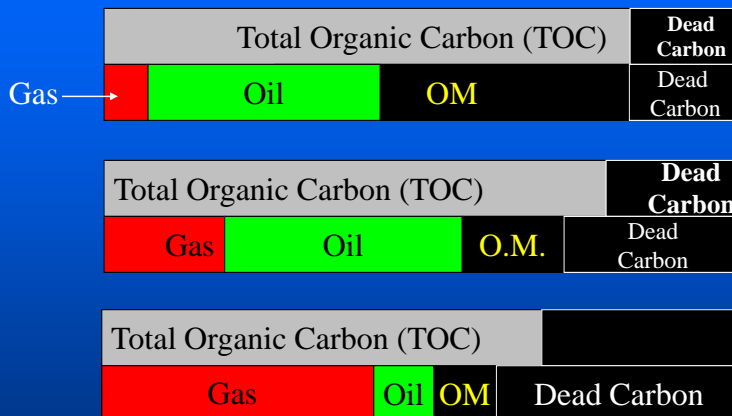
CALCULATED TRANSFORMATION RATES for BARNET OM CRACKING and OIL CRACKING to GAS



Distribution of Organic Matter in Rock Sample (low maturity)



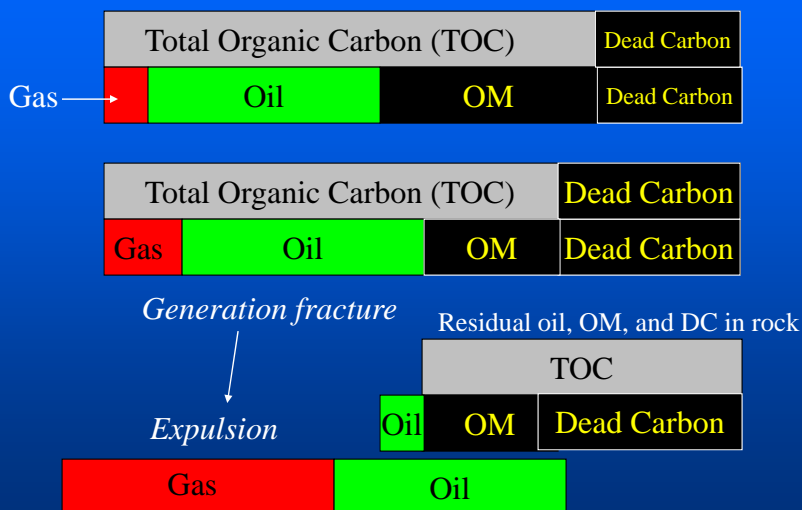
Maturation of Organic Maturity

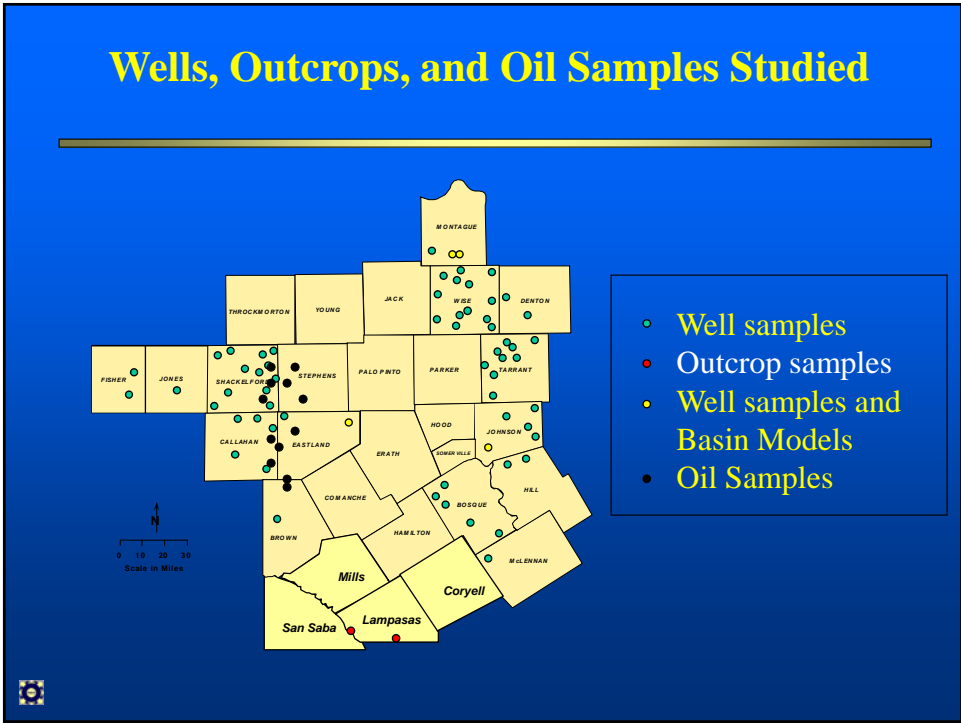
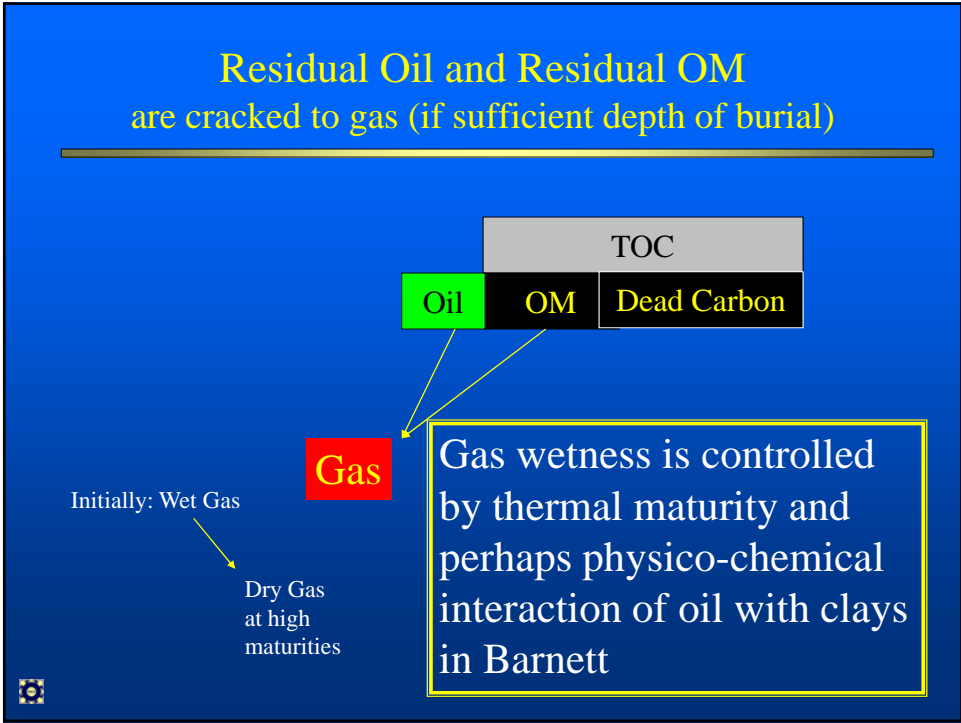


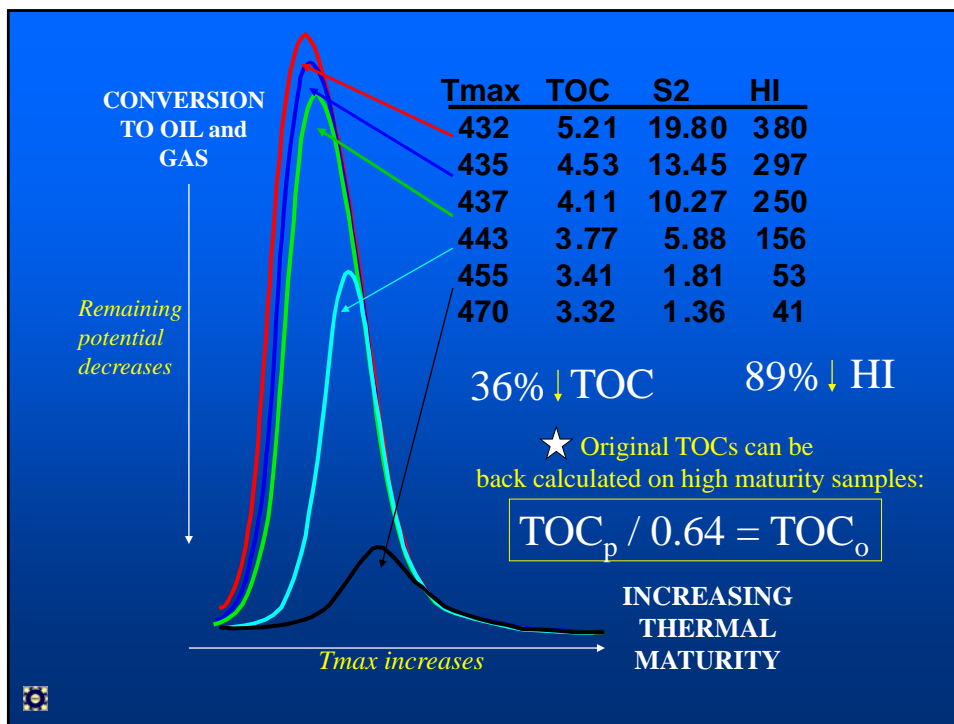
1. OM is converted to oil and gas; slight increased in dead carbon
2. 1 continues, but oil cracks to gas also



But episodic expulsion also changes the mix







Tmax-based calculation of %Ro for the Barnett Shale and other kerogens excluding Type I

- Tmax is a chemical indicator of thermal maturity
- It is kinetically controlled just like vitrinite reflectance; however, it will vary depending on kerogen type; it is especially poor for Type I source rocks (single Ea/A samples)

★ **Cal. %Ro = 0.0180 x Tmax - 7.16** ★

– R² = 0.79 (n=179)

– Sigma = 0.23

– not applicable for some samples esp. with limited S2

Barnett Shale - Ave. Values

- All Barnett (n=540)
 - 3.16 TOC
 - 2.52 S2
 - 449 Tmax
 - 23 HI
 - 21 NOC
 - 55 BO/AF
- Low maturity Barnett (n=36)
 - 3.26 TOC
 - 7.87 S2
 - 432 Tmax
 - 165 HI
 - 33 NOC
 - 172 BO/AF

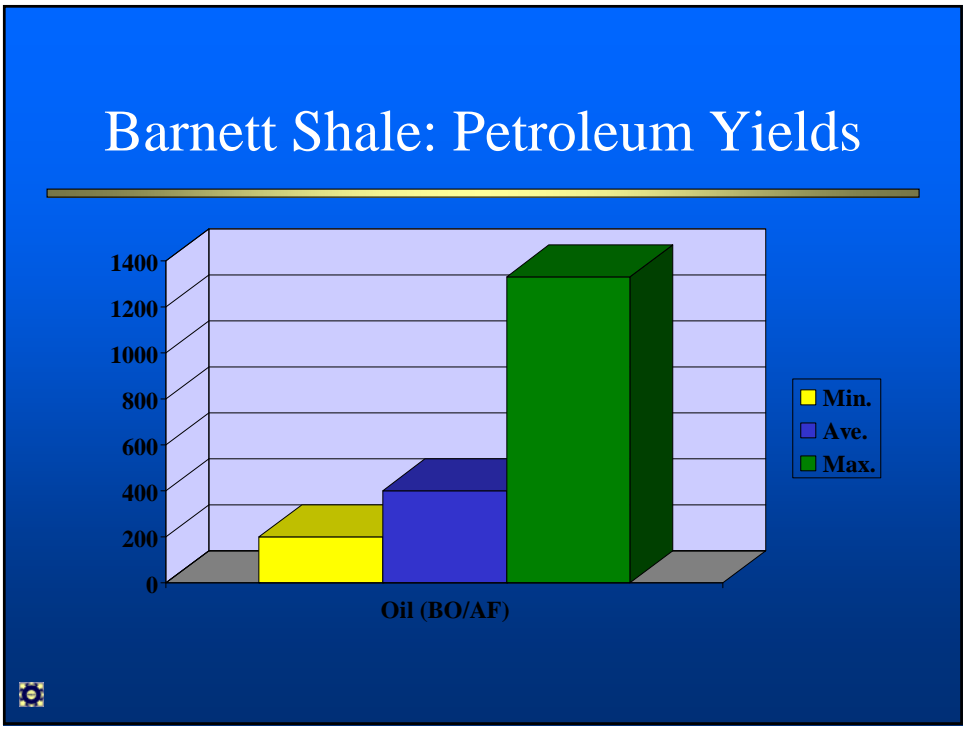
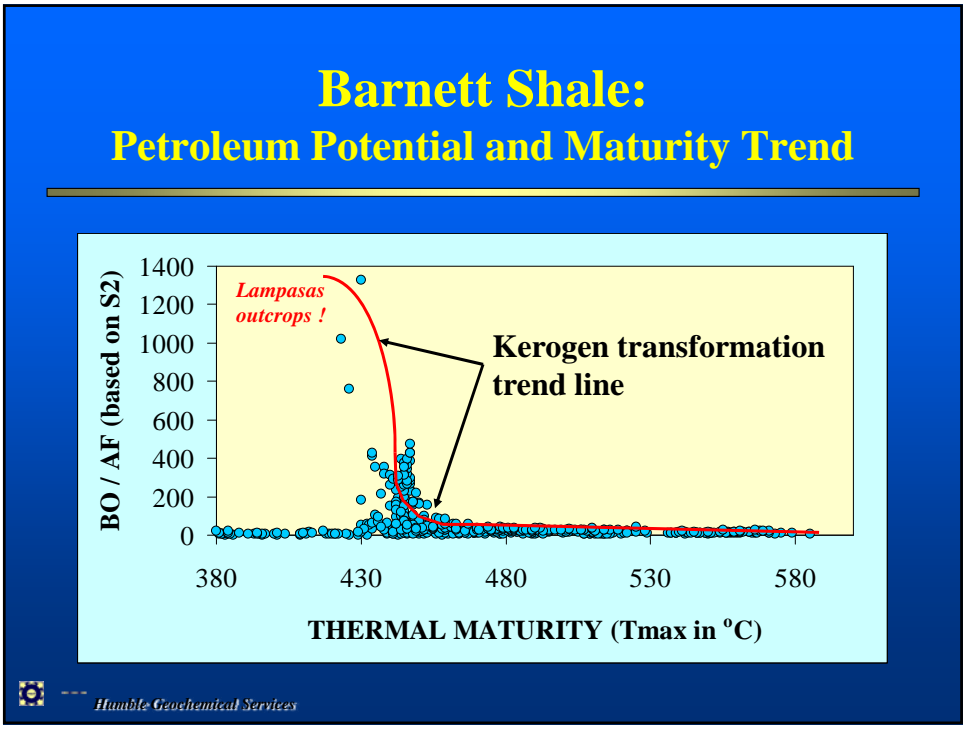
(in both cases primarily cuttings analysis)



Barnett Shale - Ave. Values

- Sims Core (n=46)
 - 4.45 TOC
 - 0.60 S2
 - 555 Tmax
 - 44 HI
 - 6 NOC
 - 13 BO/AF
- Lampasas Outcrops (n=3)
 - 11.82 TOC
 - 47.26 S2
 - 426 Tmax
 - 395 HI
 - 31 NOC
 - 1035 BO/AF





EXAMPLES OF AVERAGE SOURCE POTENTIAL INDICES

(tons HC/m²)

-
- | | |
|---------------------------------------|----|
| 1. Junggar (China): | 65 |
| 2. L. Congo (Cabinda): | 46 |
| 3. Santa Barbara Channel (U.S.A.): | 39 |
| 4. San Joaquin (U.S.A.): | 38 |
| 5. Central Sumatra (Indonesia): | 34 |
| 6. E. Venezuela fold and thrust belt: | 27 |
| 7. Offshore Santa Maria (U.S.A.): | 21 |



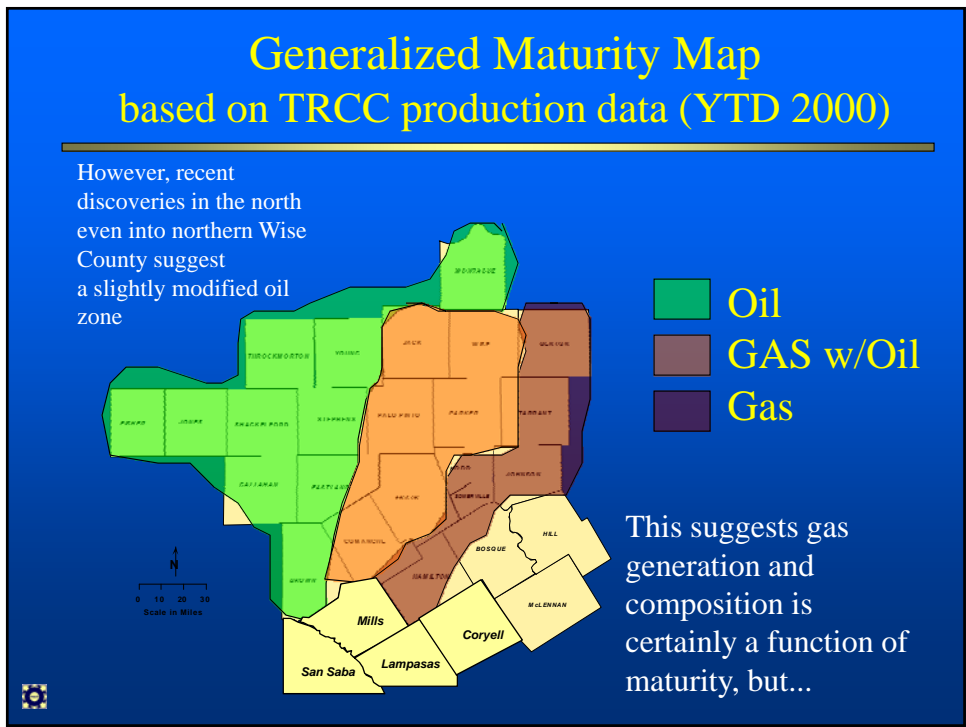
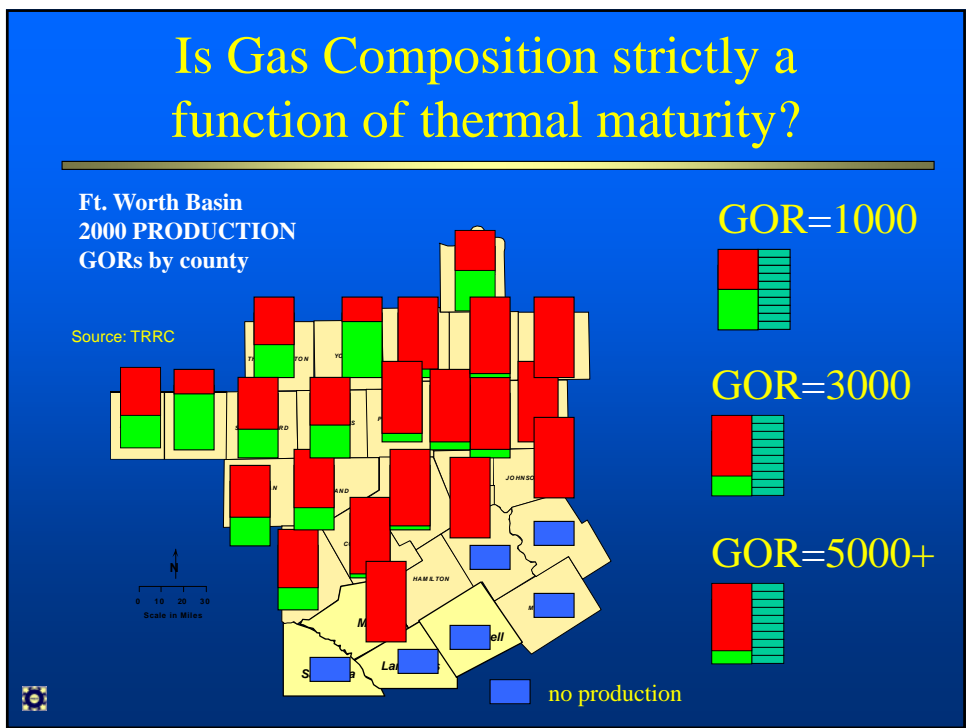
EXAMPLES OF SPI (cont.)

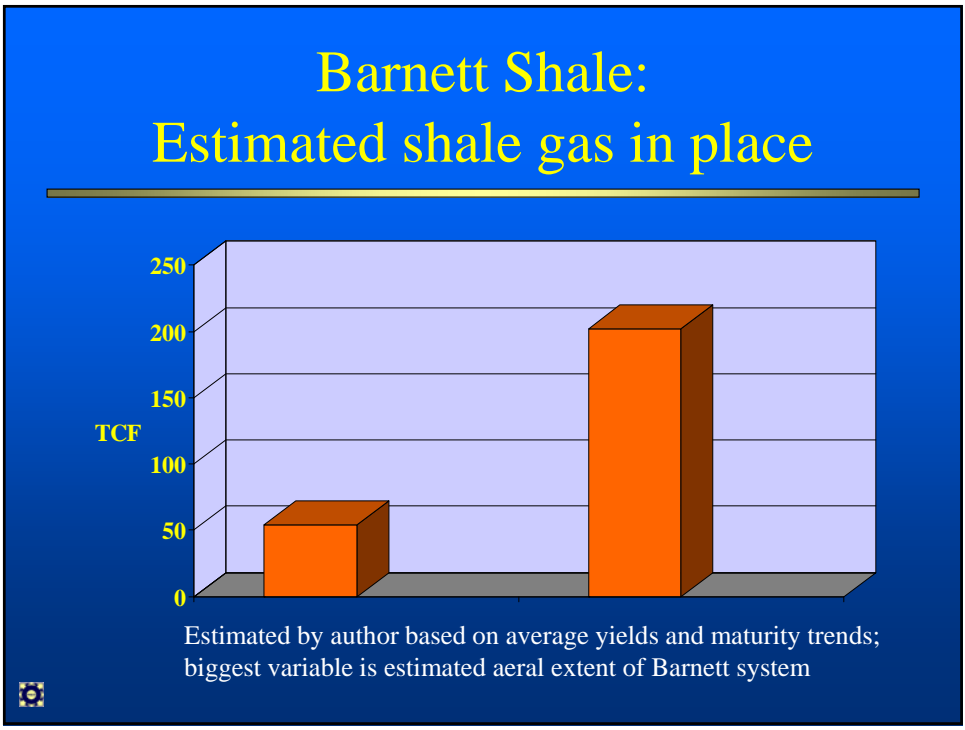
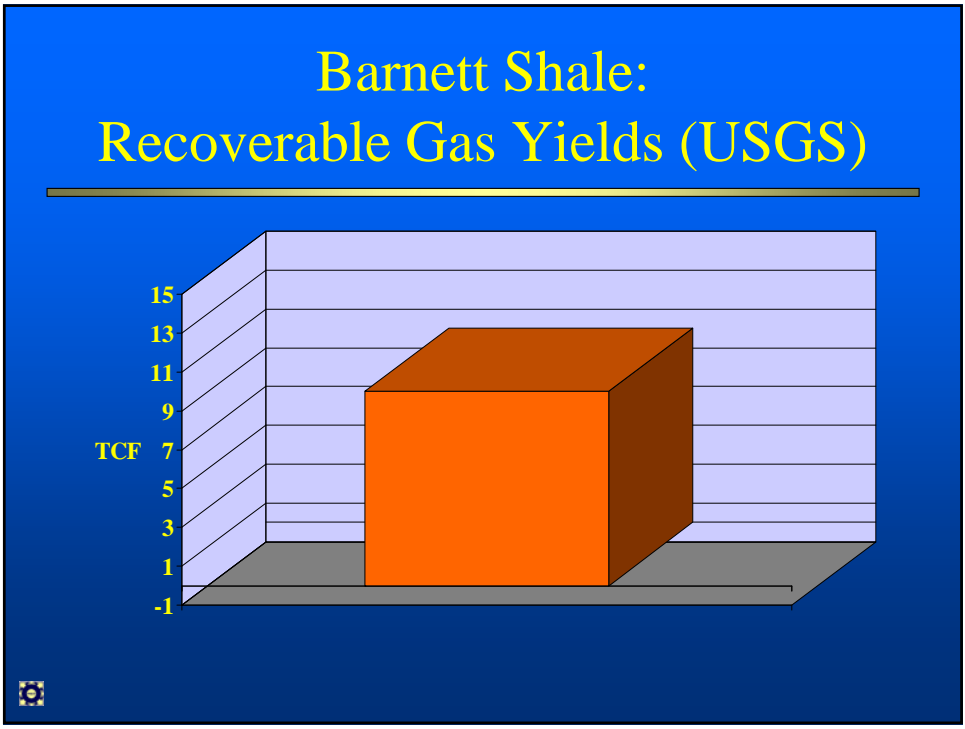
(tons HC/m²)

-
- | | |
|--|-----------|
| 8. Middle Magdalena (Colombia): | 16 |
| 9. North Sea (U.K.): | 15 |
| 10. Central Arabia (S. Arabia): | 14 |
| 11. Niger Delta (Nigeria): | 14 |
| 12. Gulf of Suez (Egypt): | 14 |
| 13. San Joaquin - Eoc./Oligo. (U.S.A.): | 14 |
| ★ 14. <u>Ft. Worth - Barnett (U.S.A.):</u> | <u>13</u> |

★ Reserves estimated at 10 TCF or ~ 1.67B BOE

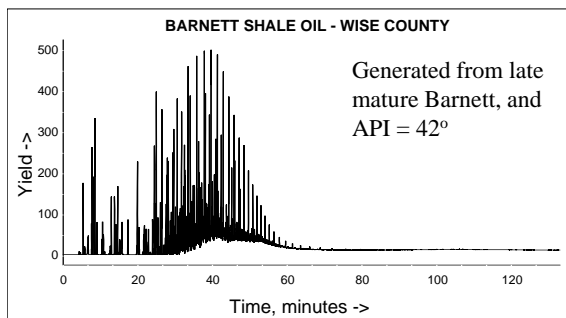
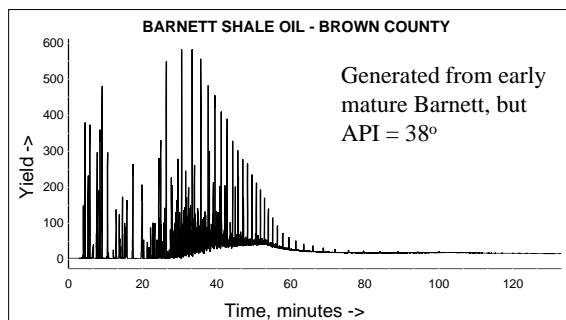
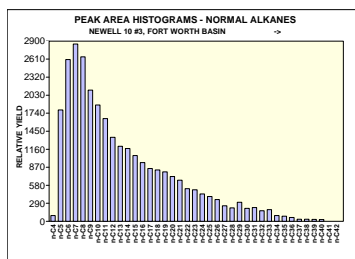
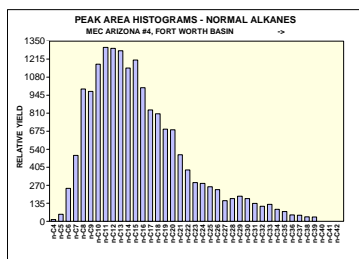
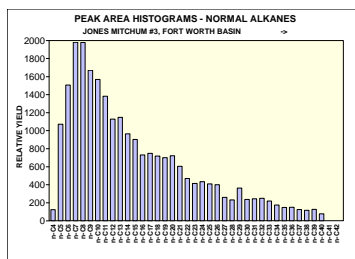
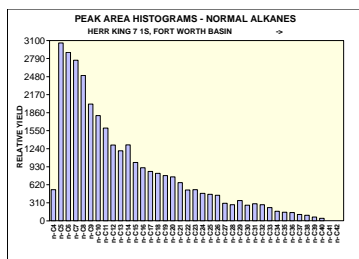






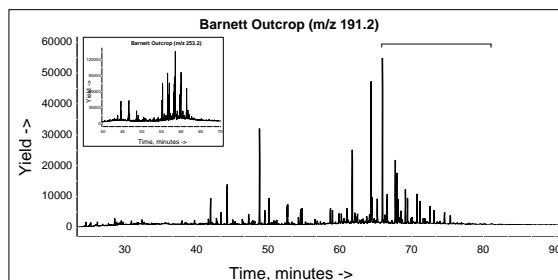
Barnett Oils: GC Histograms normal alkanes

These data show the similarity of all the oils and the high quality of oils from early mature Barnett

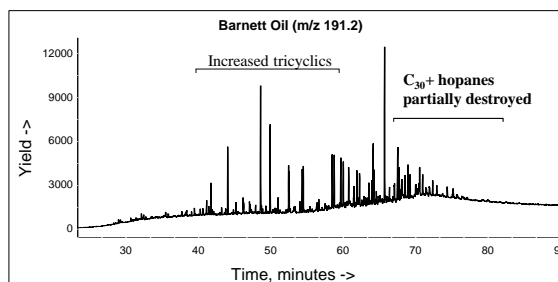


Biomarkers: outcrop vs. oil

From low maturity
Barnett outcrop
near Lampasas:
clay-rich marine
shale



From Brown County
Barnett oil production:
extended hopanes are
partially cracked resulting
in a relative increase in
tricyclic terpanes; oils in
Wise Cty have limited
biomarkers present



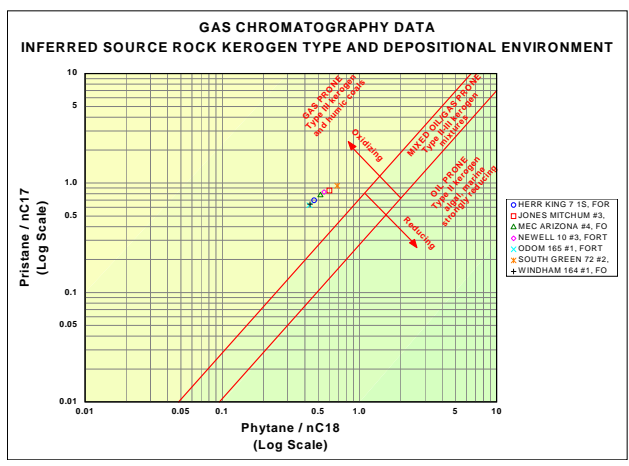
Light hydrocarbons do show lithofacies dependency

- Clay-rich source rocks have definitive characteristics in
 - biomarkers (e.g., diasteranes, tricyclics)
 - light hydrocarbons (e.g., isoalkanes, DMCPs)

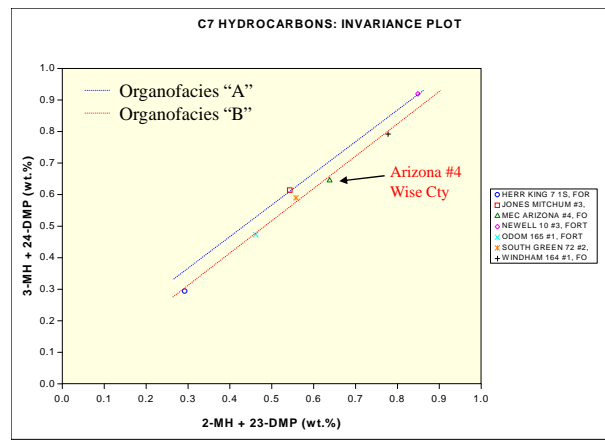
These characteristics suggest an interaction of
organic and inorganic matrices.



C₁₀⁺ GC results on oils infer that oils are from the same source with slight maturity differences



C₇ Data suggests all oils are primary, although 2 Barnett facies may be sourcing oil



Wise County oil plots with other oils from far western part of basin

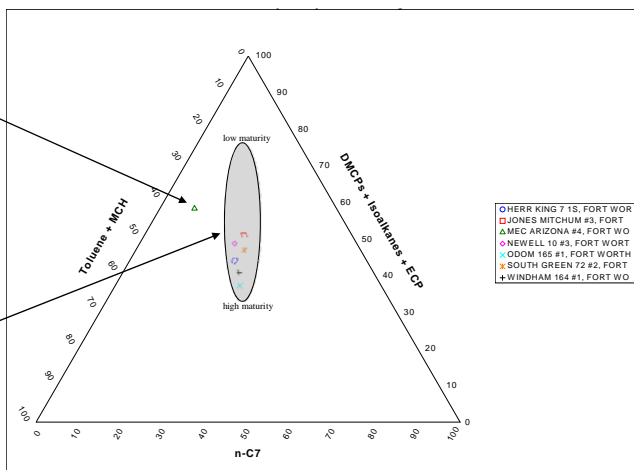
Other oils from western Ft. Worth Basin plot on separate trend line suggesting a different organofacies of the Barnett



Yet the Wise County oil appears heavily altered based on a type specific C7 plot

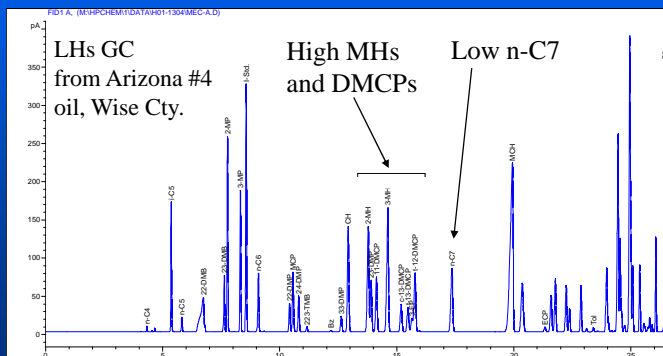
Wise Cty oil

Oils from clay-rich shales



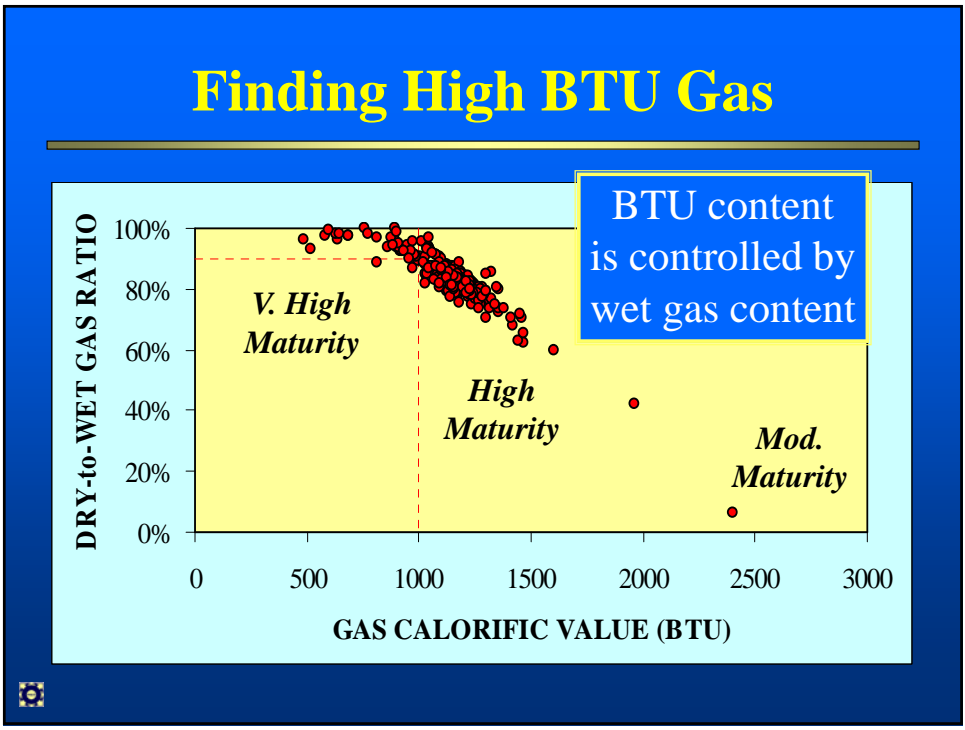
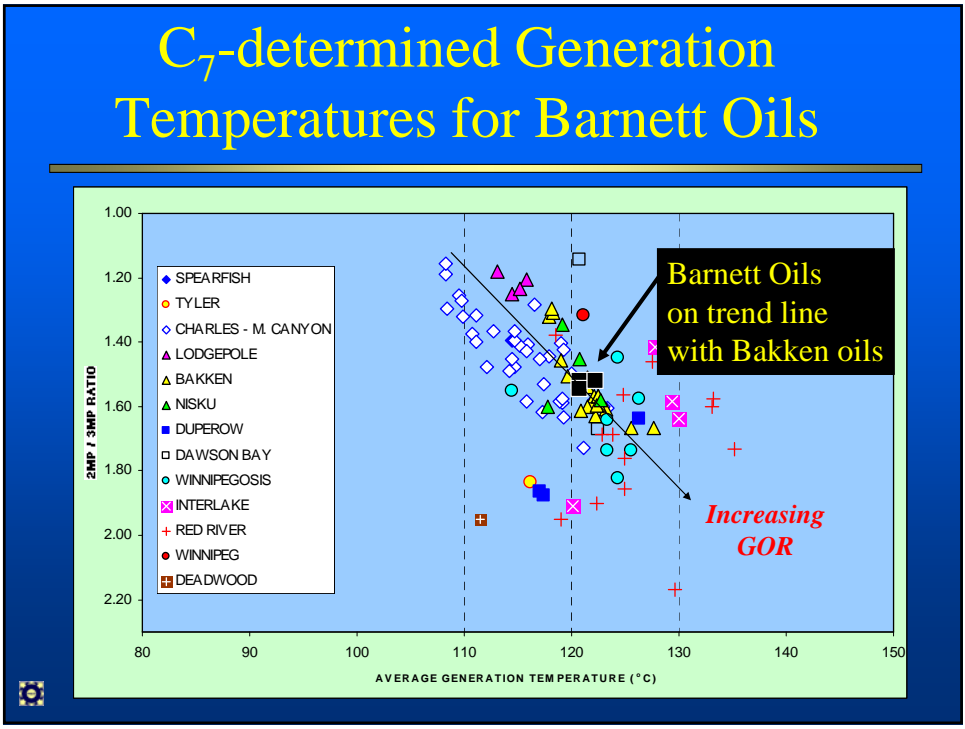
Experimental data shows that when oils are artificially matured in the laboratory with illite, there is dramatically increased yields of methylhexanes and depleted normal alkanes¹

This suggests that at higher temperatures, clays may be altering the product distributions from oil cracking. Clay catalysis tends to form wetter gas².



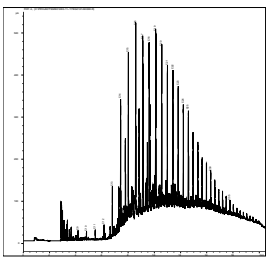
¹ Jarvie *et al.*, 2001
² Coburn *et al.*, 1987



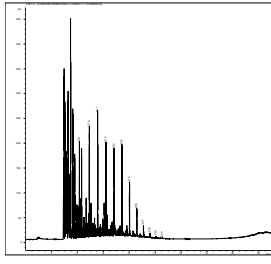



Identification of oil, wet or dry gas by fingerprinting directly from cuttings or core chips:
TEGC
Also useful for GOR prediction

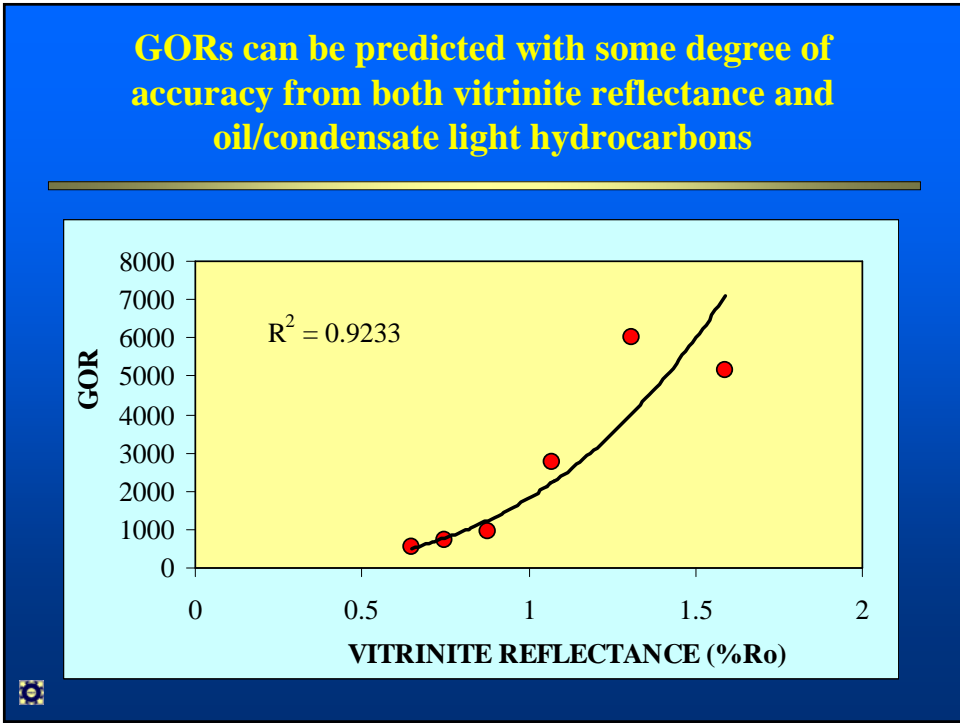
Oil Prone

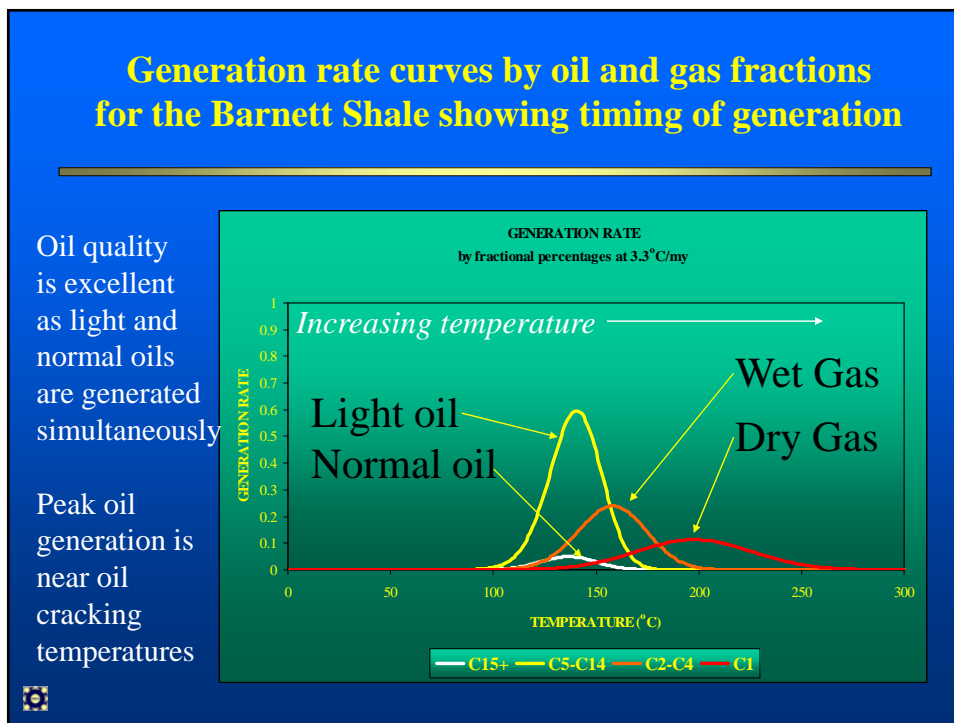
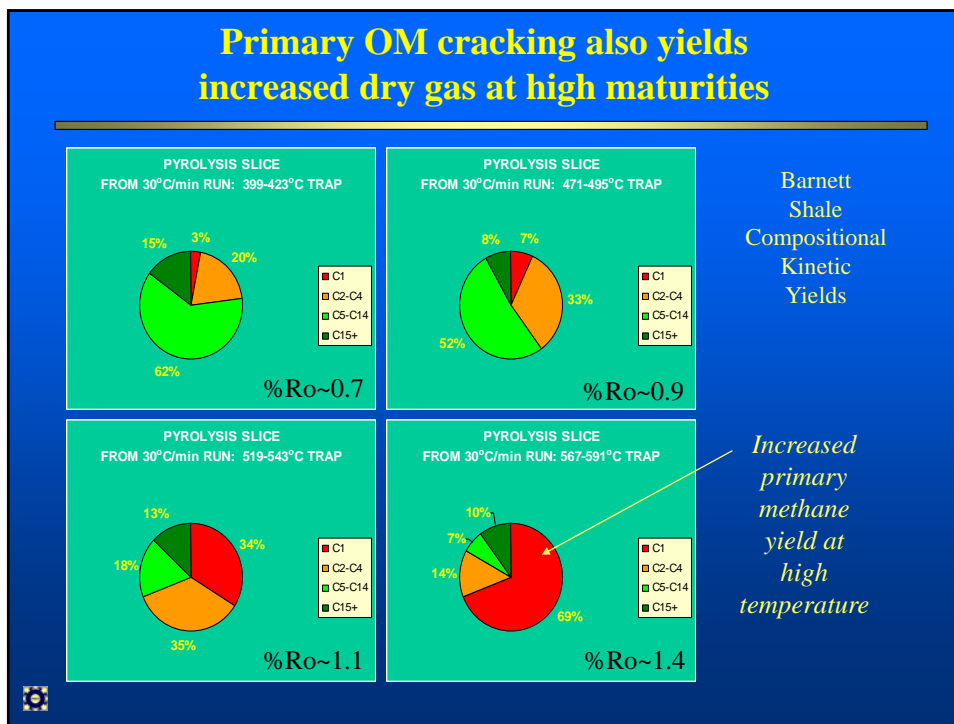


Gas Prone

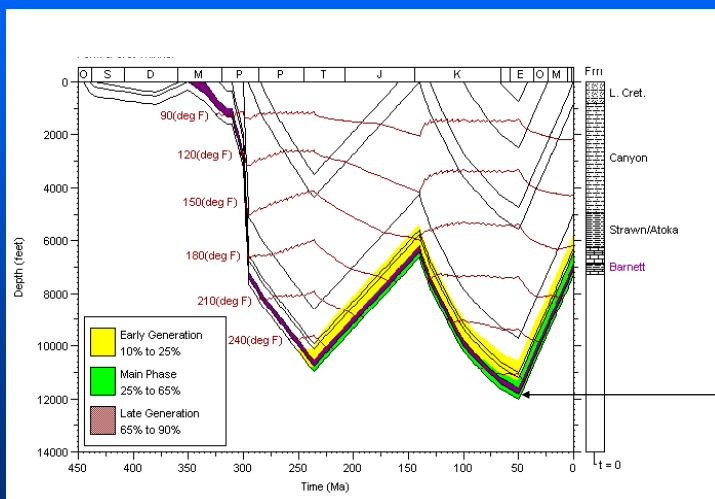






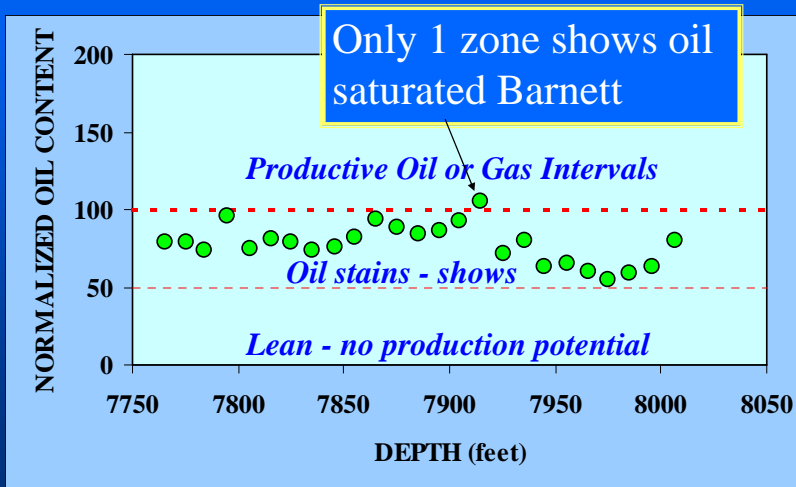


Why is there oil in Montague County? Burial History and Hydrocarbon Generation History



Maximum burial temperatures yield only oil

Why wasn't the ORYX GRANT #1 HORIZONTAL WELL COMMERCIAL FOR OIL?



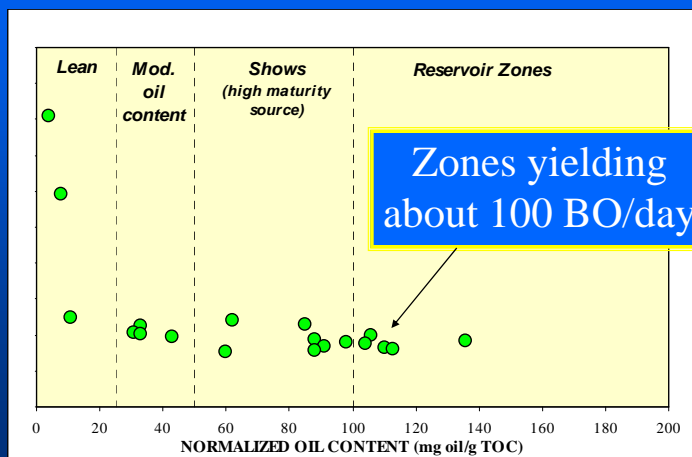
Only 1 zone shows oil saturated Barnett

Productive Oil or Gas Intervals

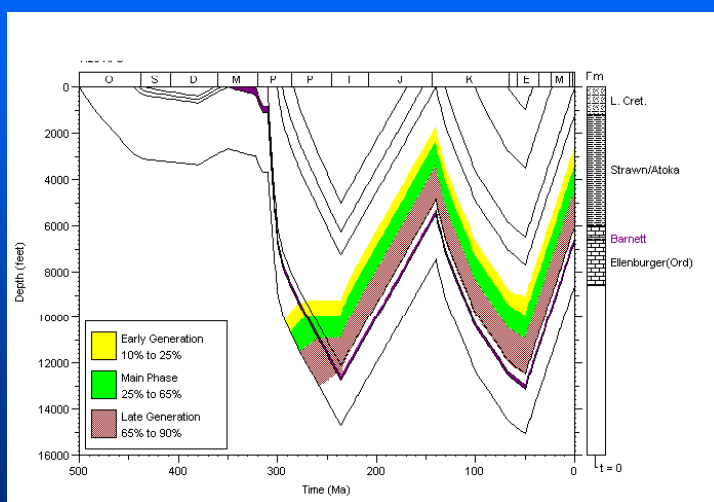
Oil stains - shows

Lean - no production potential

Other wells have commercial oil that is evident from simple tests

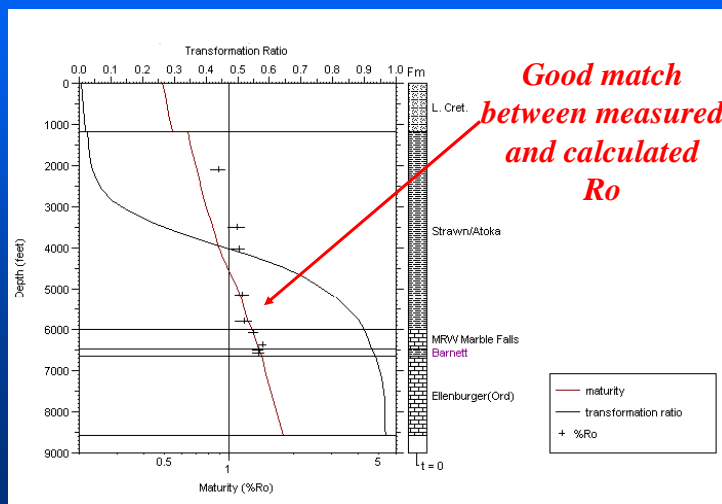


Why is there gas in Wise and Johnson Counties? Primary gas and secondary gas generation

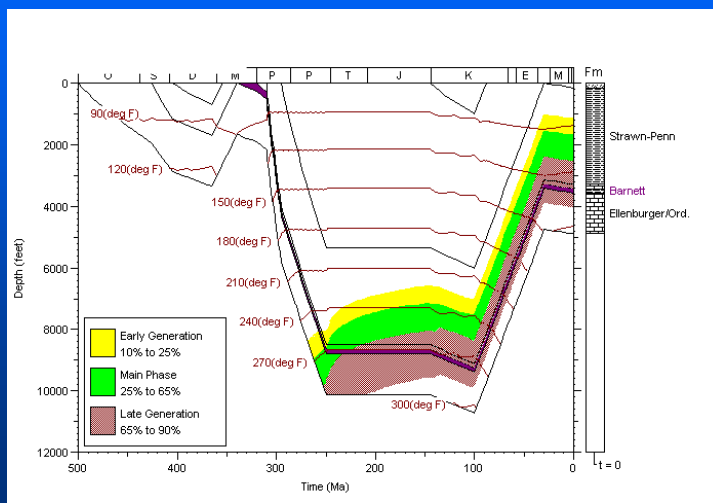


DUAL PHASE SYSTEM DUE TO GAS GENERATION FOLLOWED by PRESSURE and TEMPERATURE DROP IN LAST 50 ma

Johnson County: Calculated vs. Measured %Ro



Eastland County: Also in gas zone, different burial history



CONCLUSIONS

- Barnett Shale has world-class petroleum potential; limiting factors are
 - episodic expulsion (timing events wrong)
 - seals (leaky through time due to venting)
- Gas derived and available from
 - kerogen cracking and secondary cracking of oil (no biogenic source of gas as in Antrim)
 - recent uplift with consequent pressure and temperature drop providing a 2-phase reservoir
- Oil or gas found in a given Barnett reservoir are maturity dependent, but other processes may be playing a role in gas wetness



Analytical Program for Barnett Wells: low cost and simple

- headspace gas analysis
- TOC-Rock-Eval
- vitrinite reflectance (%R)
- thermal extract GC fingerprinting
- oil fingerprinting
- mineralogy



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