Petroleum System Charge Analysis for Liquid-Rich Unconventional Plays*

Michael Abrams [1]

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*Adapted from oral presentation given at AAPG Geosciences Technology Workshop, International Shale Plays Houston, Texas, April 28-29, 2015. Please see closely related article, "Hydrocarbon Charge Considerations in Liquid-Rich Unconventional Petroleum Systems", Search and Discovery article #80366.

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Abstract

Liquid-rich unconventional (LRU) plays have become a significant worldwide exploration target. We have seen greater emphasizes on defining the key petroleum systems factors required for a viable LRU play given the current lower price environment. Unlike the conventional system which requires off structure generation and migration, the liquid-rich unconventional petroleum system requires little or no migration. The liquid-rich unconventional acts as both source and reservoir; or the source rock is juxtaposed against or inter-bedded within the reservoir requiring minimal migration. There are many similarities to the conventional petroleum system but key fundamental differences are critical in understanding liquid-rich unconventional play potential. One must keep in mind not all organic rich oil generating source rocks will provide an economic liquid-rich unconventional petroleum system. Key petroleum system factors must be in place for an economic liquid-rich unconventional petroleum play to work (amount and type of organic matter type; source rock organic maturity; expulsion efficiency and fractionation; etc.). Having all of these factors does not guarantee the liquid-rich unconventional system will have sufficient production rates and ultimate recovery for an economic play, but not having one or more guarantees the liquid-rich unconventional system will be marginal or non-economic.

Selected References

Bohacs, K.M., Q.R. Passey, M. Rudnicki, W.L. Esch, and O.R. Lazar, 2013, The Spectrum of fine-grained reservoirs from 'shale gas' to 'shale oil' tight liquids: Essential attributes, key controls, practical characterization: International Petroleum Technology Conference, EAGE, abstract.

Jarvie, D.M., 2001, Williston Basin petroleum systems: Inferences from oil geochemistry and geology: The Mountain Geologist, v. 38, p. 19-41.

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Petroleum System Charge Analysis for Liquid Rich Unconventional Plays*

Michael A. Abrams

Apache Corporation

- ✓ *Why is not every high quality organic rich source rock an excellent liquid rich unconventional resource play?*
- ✓ *What critical petroleum systems elements are required to make an economic liquid rich unconventional resource play?*

Talk Outline

1. Introduction
2. Defining Liquid-Rich Unconventional Play "shale oil"
3. Parameters Critical for Economically Successful LRU
4. Assessing *Oil in Place* and *Movable Hydrocarbons*
5. Key Take Aways

* Based on 2013 AAPG GTW keynote lecture and 2014 Unconventional Resources Technology Conference lecture.

Apache

1. Introduction

Parameters Critical for Economically Successful LRU Play

	Parameter
SIZE	Scope
	Thickness
	Depth
RICHNESS	Shows
	OOIP
SOURCE	Level of Maturity
	TOC
HC	Oil Quality
FLOW	Permeabilty
	Porosity
	Pressure
Landing Zone	Thickness
	Definition
COMPLETION	Mineralogy
	Young's Modulus
	Poisson's Ratio
	Stress
	Seals

Modified from Craig Rice, Apache

Charge System

- Total Organic Carbon: how much organic carbon.
- Organic matter type: type of organic matter.
- Rock maturity: maximum temperature.
- Migration: expulsion versus retained hydrocarbons.

Production

- Fluid properties: original/changes with production.
- Storage: where is hydrocarbon stored.
- Flow: rock permeability, porosity, and pore pressure.
- Completions: rock properties critical to fracability.

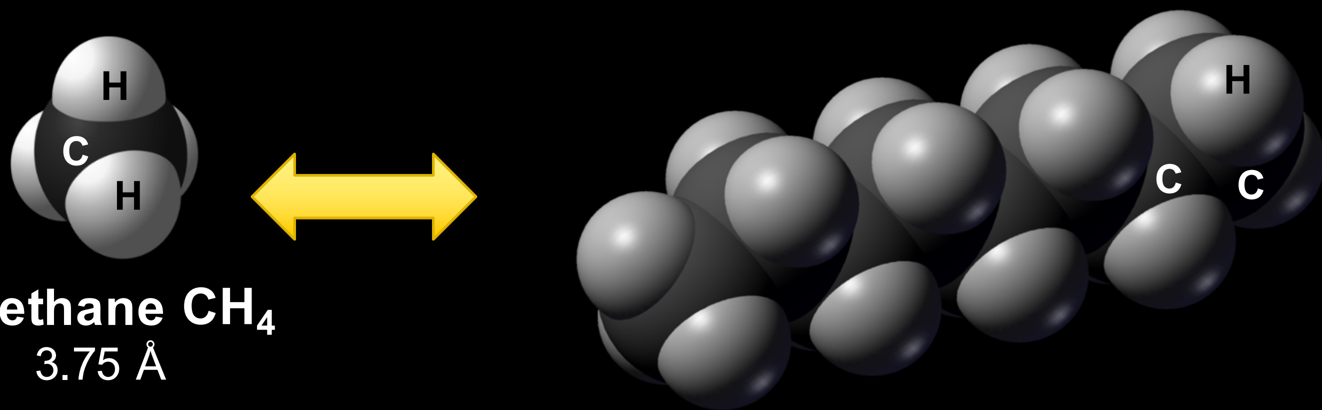
Economics

- Drilling cost: location and depth.
- OOIP: how much oil is in place.
- EUR: how much can you produce and at what rate.

Technical Distinctions between Gas and Liquid Systems

Size matters (at least in gas versus liquids)

☞ size of molecule relative to pore throat size is critical.



Methane CH_4
3.75 Å

Octane
C_8H_{18}
length 13.17 Å
height 4.85 Å

Thermal Maturity Window

☞ *GAS* – Overmature versus *LIQUIDS* – Mid to Late Mature

Molecular Interactions: Gas versus Liquid Forces

gases – molecular interactions (Van der Waals) versus *liquids* – viscous.

Shale gas learning's are of limited use in liquid rich unconventional system.

2.0 Defining Liquid-Rich Unconventional Play

"fine-grained rock acting as both hydrocarbon★ source and reservoir, or a low permeability reservoir with inter-bedded or juxtaposed organic-rich shale with liquid hydrocarbon potential"

Abrams (2014)

Broader Definition: *Reservoir which requires significant stimulation to provide economic liquid production rates*.

System Type	Characteristics	Secondary migration	Poro-Perm Components	Examples
1 – 'Conventional' Tight *Reservoir ≠ Source*	Tight SS, siltstone, carbonate interbedded w/ lean, immature source rock; Black oil to dry gas	Significant		*Spraberry* *Lewis Shale* *Mancos* *Mesa Verde*
2 - Hybrid/Interbedded *Reservoir ≠ Source*	Tight SS, siltstone, carbonate interbedded w/ rich, mature source rock; Light oil to dry gas	Moderate		*Bakken* *Bone Springs* *2nd White Specs*
3 - Porous Mudstone *Reservoir = Source*	Source rocks with significant inter/intra-grain porosity at oil to gas/condensate level of maturity; includes organic-hosted porosity	Minimal		*Eagle Ford* *Haynesville* *Barnett* *Woodford*
4 - Fractured Mudstone *Reservoir ± = Source*	Mature source rocks with significant fracture porosity; Heavy oil to dry gas	Minimal		*Monterey* *Woodford* *Austin Chalk* *Barnett*

From Bohacs et al. (2013)

End Members

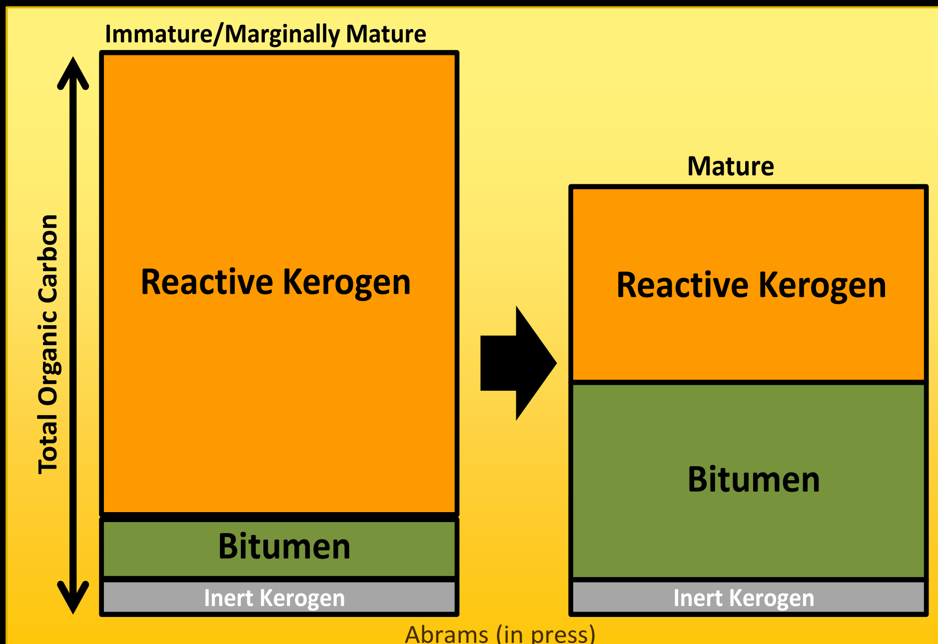
- *Eagle Ford* (porous mudstone):
  - ☞ source = reservoir/no migration.
- *Bakken* (hybrid/interbedded):
  - ☞ source ≠ reservoir/migration.

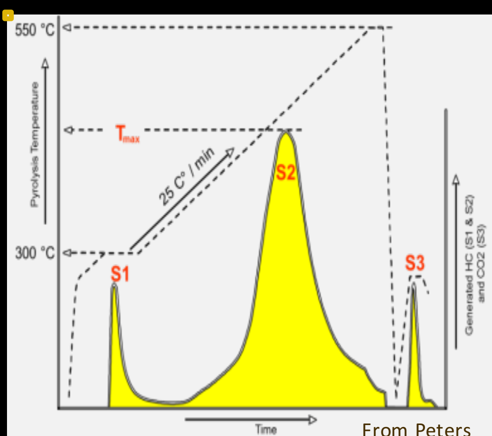
✓ *Source versus reservoir* → same, juxaposed, or off structure charge?

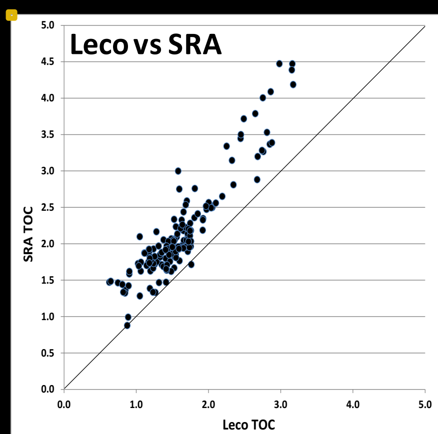
★*Hydrocarbon*: to include hydrocarbon and non-hydrocarbon (NSO) compounds.

3.0 Parameters Critical Economically Successful LRU Play

3.1 Type and Amount of Organic Matter







Total Organic Carbon (TOC)

- What is *Total Organic Carbon*?
  - ✓ Reactive kerogen
  - ✓ Inert Kerogen
  - ✓ Bitumen (generated HC)
- How do you measure TOC?
  - ✓ *Leco*: Rock pulverized, sieved, reacted with hydrochloric acid, dried. accelerator added, and CO_2 quantitatively measured.
  - ✓ Calculated from programmed pyrolysis:

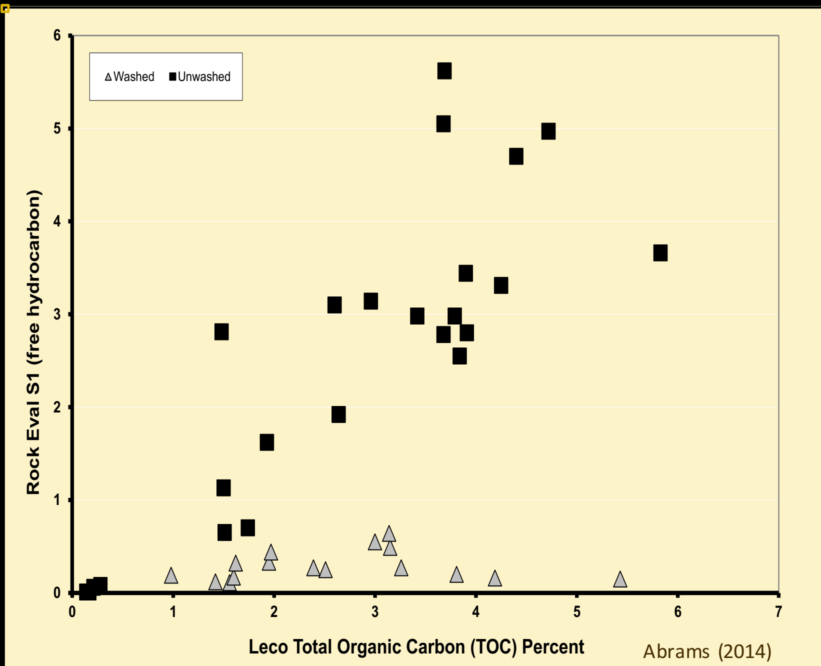
SRA TOC = k (S1 + S2) x S4 / 10

Where k = 0.83 (the average carbon content of hydrocarbons based on atomic weight)

S1: hydrocarbons present in a free or adsorbed state during pyrolysis volatilized at moderate temperatures [mg/g rock].
S2: hydrocarbons and hydrocarbon-like compounds which are set free at increased temperatures [mg/g rock].
S4: *residual carbon* obtained from SRA plus TOC oxidation oven. The residual fraction (S4) oxidized dead carbon and does not contain potential to generate hydrocarbons.

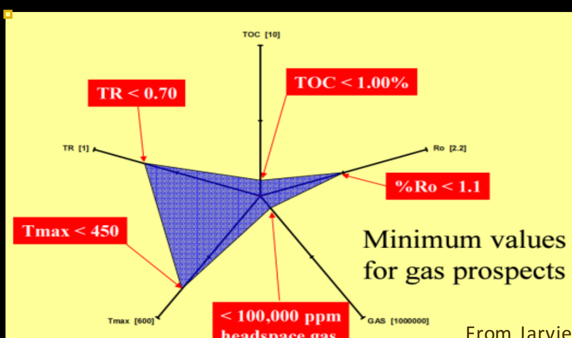
→ **Leco & SRA DO NOT provide same result!**

3.1 Type and Amount of Organic Matter, cont.



Factors that impact TOC measurement:

- **Organic maturity.**
  - TOC will decrease with maturity
  - bitumen vs kerogen
- **Generated (free) hydrocarbon:**
  - Heavier free hydrocarbons (> C_{50}) and non-hydrocarbons (resins, asphaltenes) will vaporize/crack higher temperatures.
- **Carbon based mud additives:**
  - oil based mud (diesel, crude, synthetic,….).
  - carbon lost circulation (BaraBlok, SteelSteal,..)

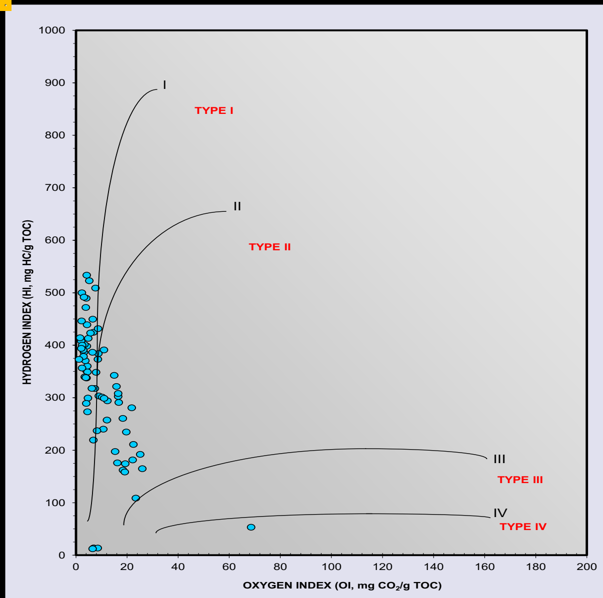


What is minimum TOC required?

No right answer………. but TOC_o less than 1.5% is a general cut off used by many.

- ✓ *TOC critical in evaluating liquid rich unconventional plays.*
- ✓ *Important to understand how and what you are measuring.*

3.1 Type and Amount of Organic Matter, cont.



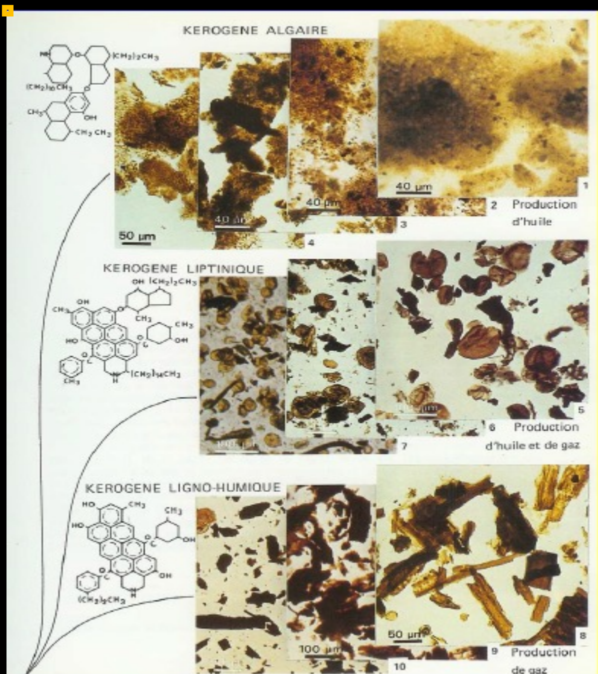
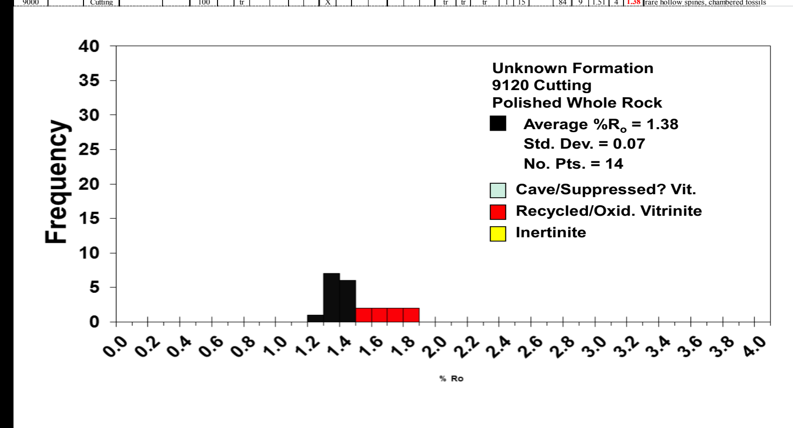


Image courtesy of Héctor Villar

Organic Matter Type (quality)

- Organic matter type determination?
  - ✓ programmed pyrolysis (HI, OI,…).
  - ✓ visual kerogen analysis (VKA).

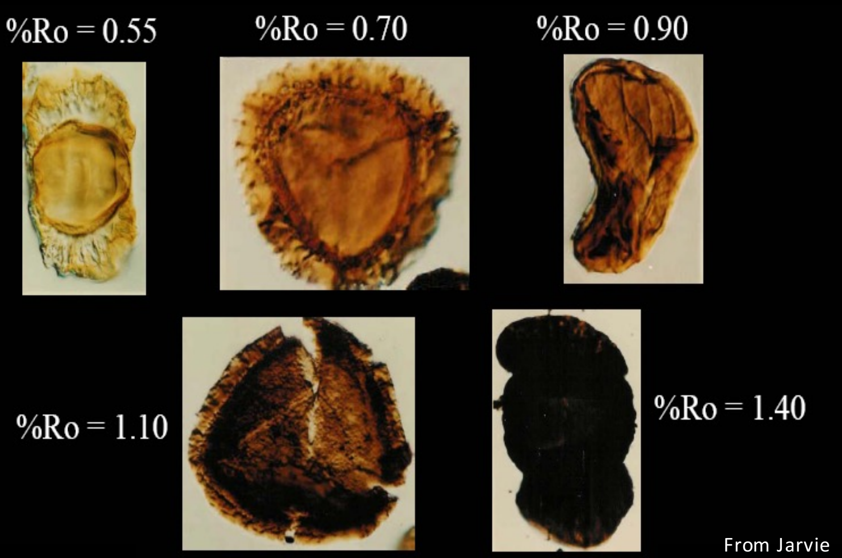
					% Source Material							Preservation				Recovery			% Kerogen Comp.							Vitrinite				
Depth 1 (ft.)	Depth 2 (ft.)	Type	Color	TAI	Amorphous Debris	Finely Dissem. OM	Herb. Plant Debris (Vit.)	Woody Plant Debris	Coaly Fragments	Algal Debris	Palynomorphs	Good	Fair	Poor	Very poor	Good	Very Poor	Barren	Indigenous Vitrinite	Caved Vitrinite	Recycled/Oxidized Vitrinite	Inertinite	Solid Bitumen	Drilling Additive/Contamination	Amorphous Kerogen	# of Readings	Total Sample Ro (%)	# of Indigenous Readings	Indigenous Ro (%)	*Comments*
8940		Cutting			100		tr					X							tr	tr	tr	1	10		89	13	1.42	3	1.27	rare hollow spines
9000		Cutting			100		tr					X							tr	tr	tr	1	15		84	9	1.51	4	1.38	rare hollow spines, chambered fossils



- Key hydrocarbon information:
  - ✓ Generation kinetics (timing).
  - ✓ Product type and phase (oil versus gas).
  - ✓ Molecular composition (SARA).

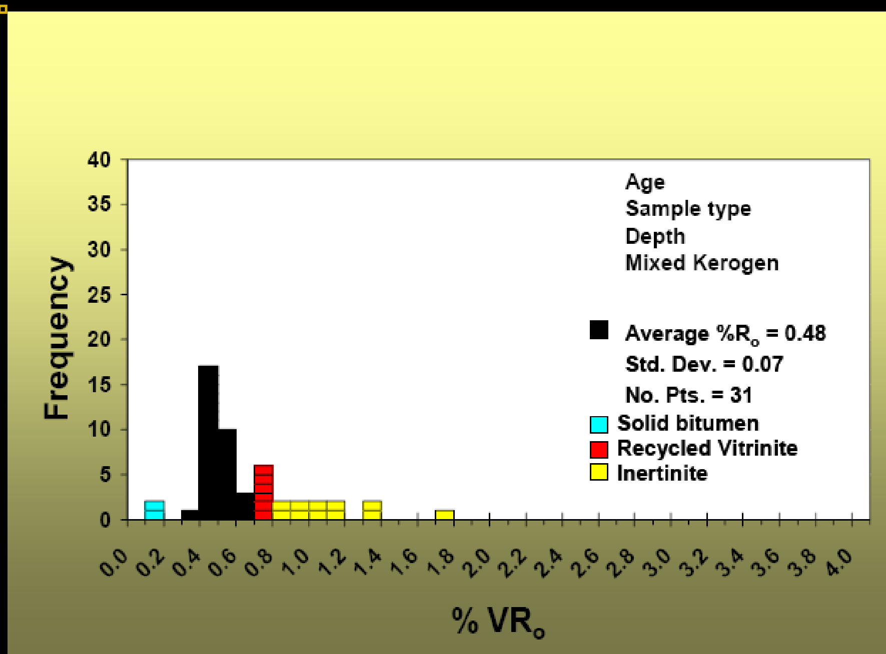
OMT impacts hydrocarbon phase and type, as well as movable versus immobile hydrocarbons.

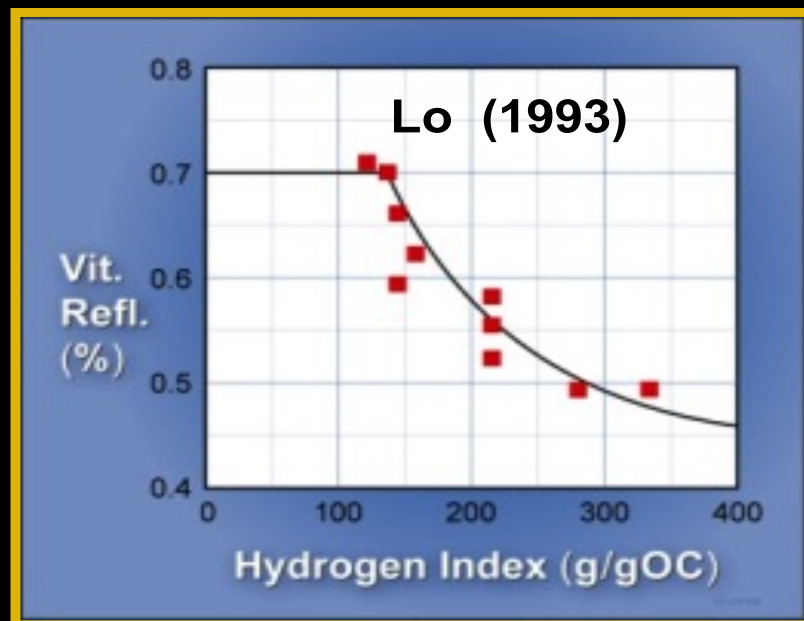
3.2 Organic Maturity



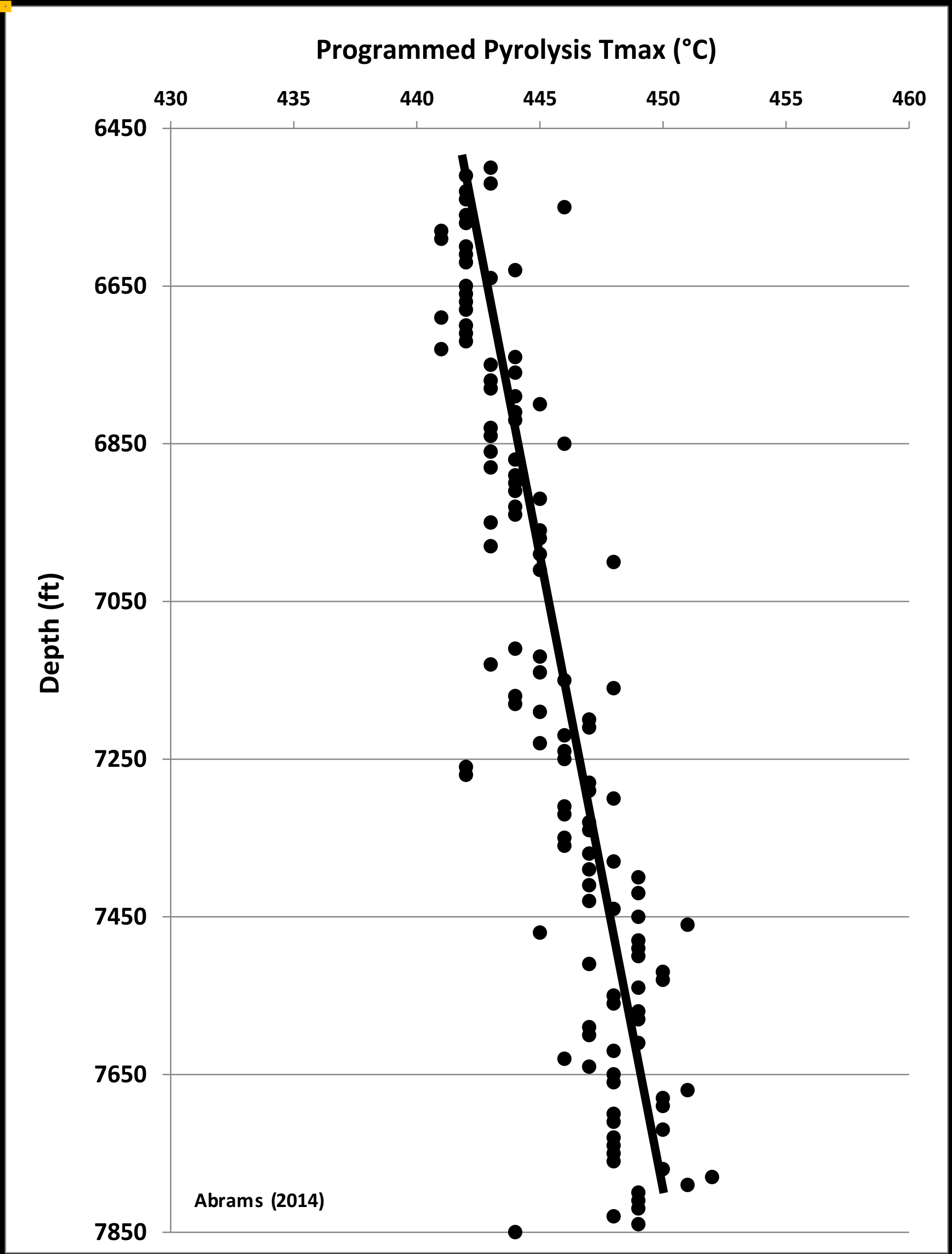
From Jarvie

- What is optimal maturity window?
- How to measure organic maturity?
  - ✓ Vitrinite Reflectance – *Ro or VR*.
  - ✓ Programmed pyrolysis - *Tmax*.
  - ✓ In situ generated hydrocarbons.
- Potential issues *Vitrinite Reflectance*:
  - ✓ proper QC (number in-situ VR,……).
  - ✓ vitrinite reflectance suppression.
  - ✓ reworked vitrinite material.
  - ✓ absence vitrinite, age or deposition.





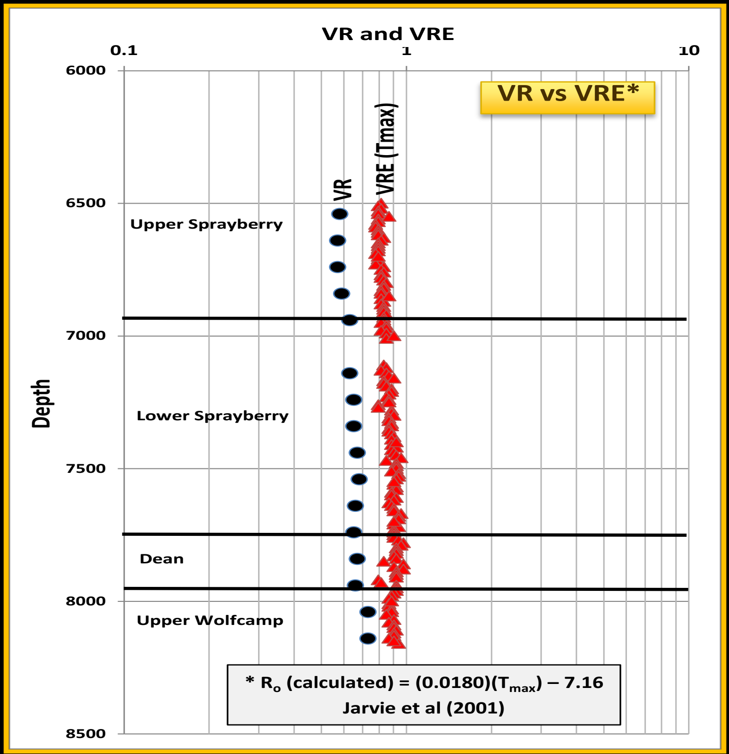
3.2 Organic Maturity, cont.



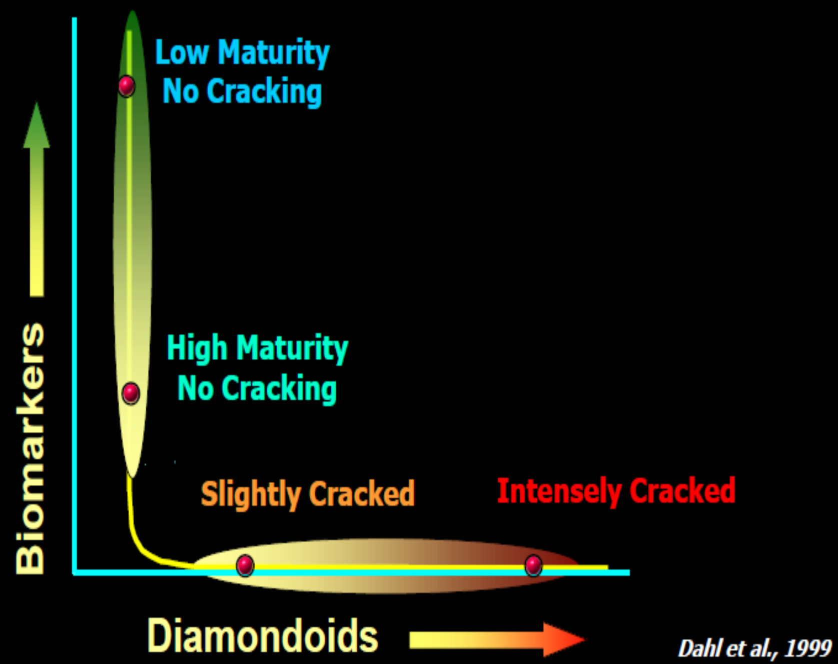
Programmed Pyrolysis Tmax

Temperature at peak hydrocarbon generation (S2) during pyrolysis [°C].

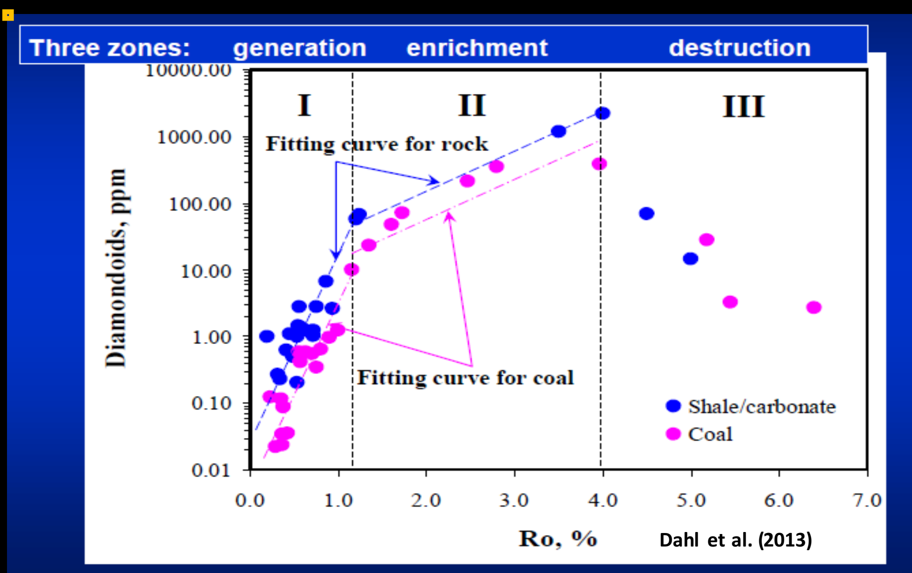
- Potential issues with Tmax:
  - ✓ different instruments (Rock eval/SRA).
  - ✓ conversion Tmax to VRE.
  - ✓ limited to immature to mature rocks.
  - ✓ variability and interpretation.



3.2 Organic Maturity, cont.



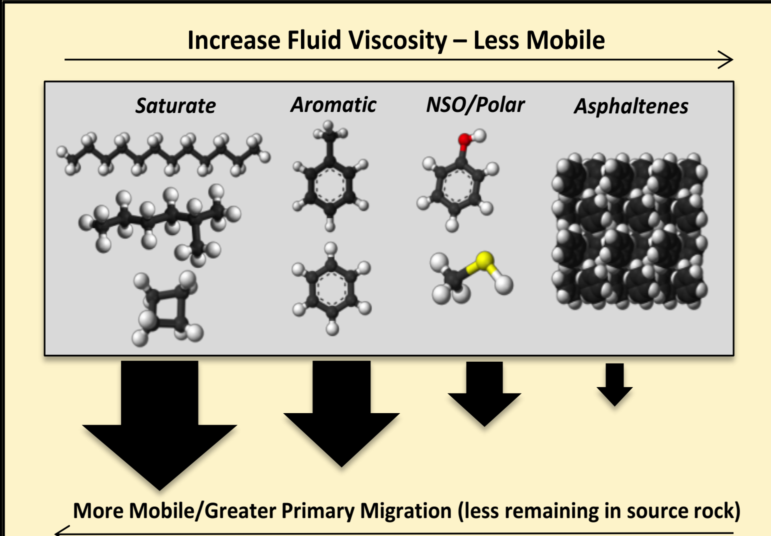
- **Maturity from in-situ hydrocarbons.** *Diamondoids* and other compounds can be used as proxy for direct measurement of oil cracking (level of organic maturity).
- **Potential issues:**
  - ✓ impact of extraction.
  - ✓ volatile loss with cuttings.
  - ✓ migrated fluids (not in-situ).



Maturity	VRE range[1]	T_{max} range[1,2]	TR Transformation	Comments
Immature	Less than 0.5	Less than 435°C	0	No S1 (free hydrocarbons) present.
Early Mature	0.5 to 0.7	435°C - 440°C	10	Early bitumen with characteristics consistent with low maturity hydrocarbon generation.
Mature	0.7 to 1.0	440°C - 450°C	50	Molecular composition consistent with full maturity oil and gas.
Late Mature	1.0 to 1.3	450°C - 470°C	90	Molecular composition consistent with late maturity oil and gas.
Overmature	1.3 to 1.8	470°C plus	100	Predominantly light oil and gas generation.
Supermature	1.8 plus	NA	100	Maturity calculation very difficult in super mature rocks.

Organic maturity impacts generation timing, fluid type and phase as well as organic porosity.

3.3 Expulsion Efficiency/Secondary Reactions



Abrams (2014)

Microfractures in organic rich shale. Hunt, 1995.

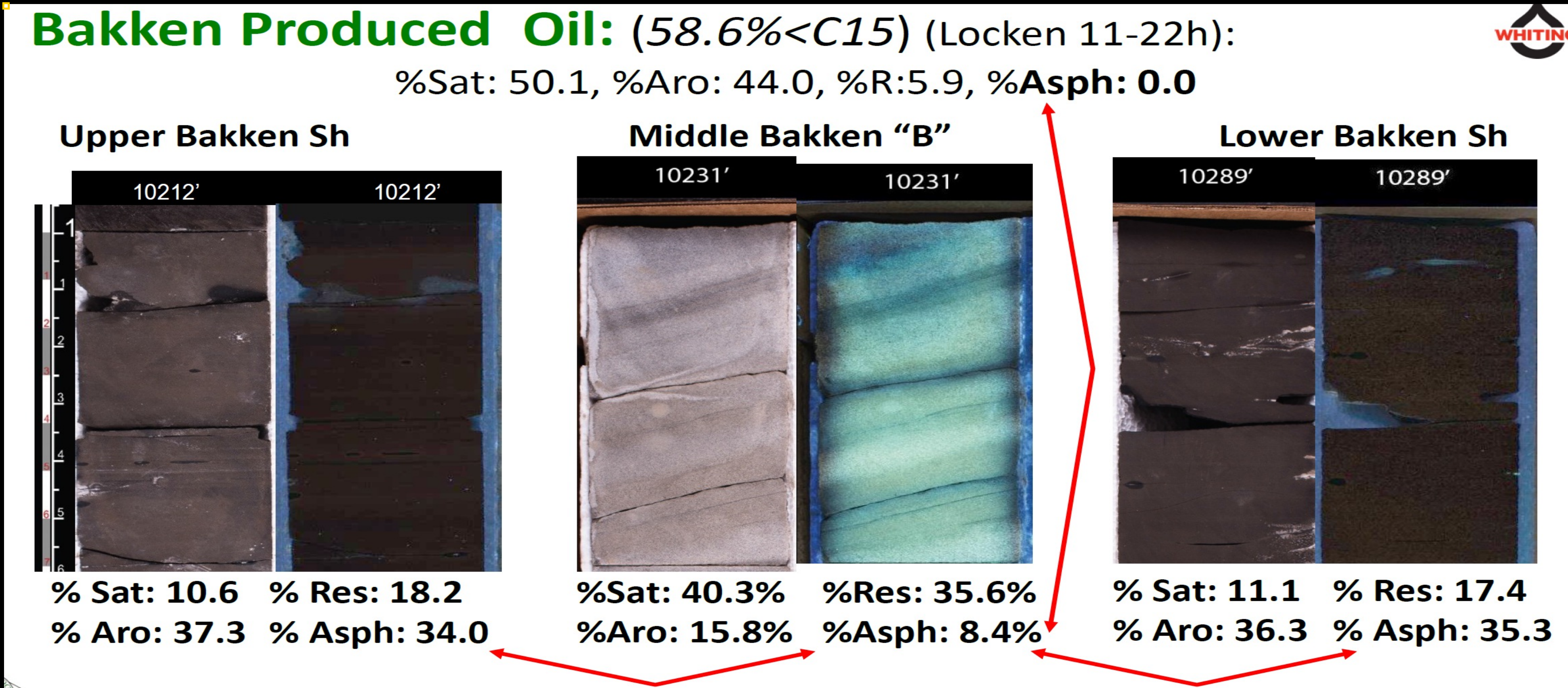
- **How much generated hydrocarbon is retained?**
  - **Modeling programs % pore volume or weight.**
- **Which compounds remain (less mobile)?**
  - **Asphaltenes/Resins-Polars/Aromatics/Saturates**
- **Secondary reactions: minerals and organic residues → coats minerals can be resistant to maturity driven chemical change.**

Other items:

- ✓ **Role hydrocarbon generation micro fracturing?**
- ✓ **Compound fractionation during production?**

Primary migration impacts how much hydrocarbon remains within source rock and/or local reservoir as well as type of hydrocarbons.

Primary Migration – Production Fractionation



Sonnenfeld and Canter (2015) *How mobile is your oil saturation. 2015* HGS Applied Geoscience Conference Houston Texas

Source Rock (52% Res & Asph)

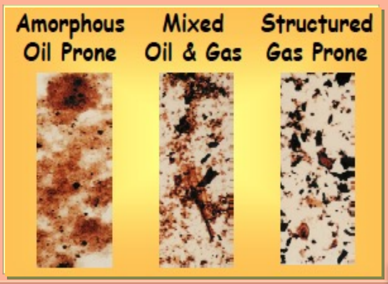
Reservoir Rock (44% Res & Asph)

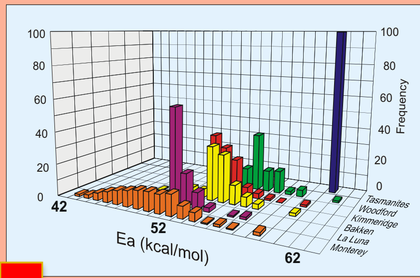
Produced Oil (6% Res)

UCR oils can be expected to be chemically different to oil in conventional reservoirs.

3.4 Fluid Properties/System

Organic Matter Type





Thermal Stress

Maturity	VRE range[1]	T_{max} range[1,2]	Comments
Immature	Less than 0.5	Less than 435°C	No S1 (free hydrocarbons) present.
Early Mature	0.5 to 0.7	435°C - 440°C	Early bitumen with characteristics consistent with low maturity hydrocarbon generation.
Mature	0.7 to 1.0	440°C - 450°C	Molecular composition consistent with full maturity oil and gas.
Late Mature	1.0 to 1.3	450°C - 455°C	Molecular composition consistent with late maturity oil and gas.
Overmature	1.3 to 1.8	455°C plus	Predominantly light oil and gas generation.
Supermature	1.8 plus	NA	Maturity calculation very difficult in super mature rocks.

Hydrocarbon Type

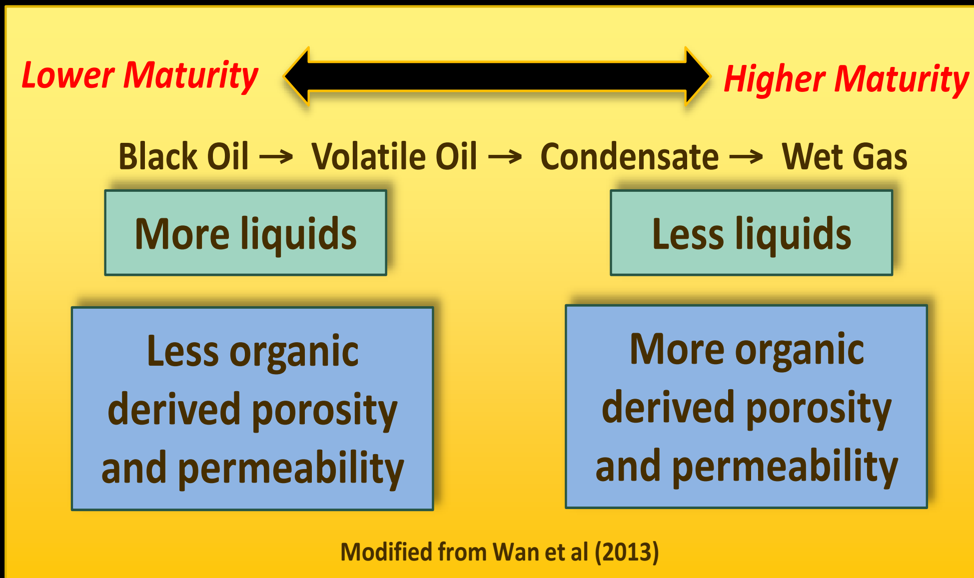
- Black oil
- Volatile oil
- Condensate
- Wet gas
- Dry gas

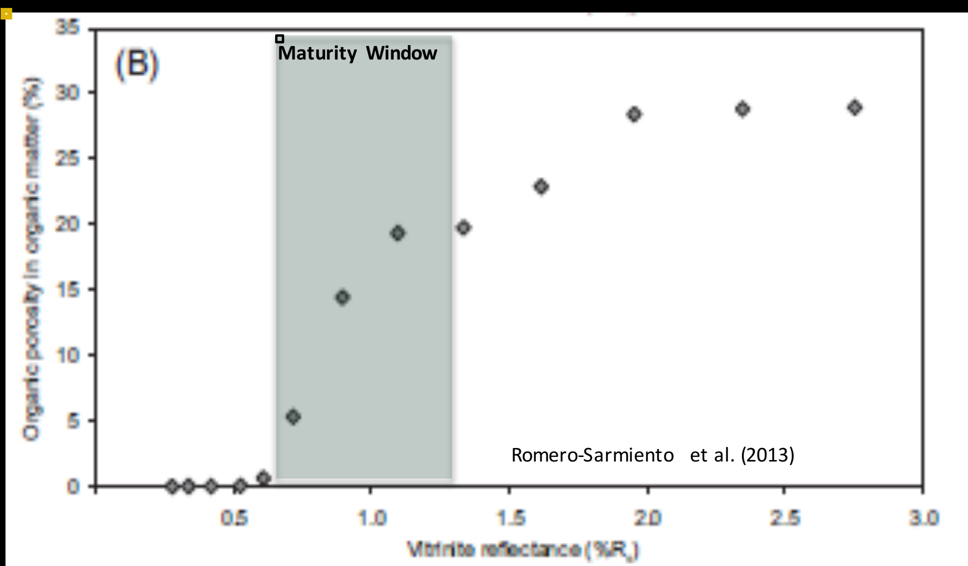
- **Type of fluid system will have impact on production rates;**
  - ***Under-Saturated*** **(dead oil)**
  - ***Saturated*** **(black to volatile oil)**
  - ***Liquids Rich Gas*** **(condensate)**
- **Fluid type driven by:**
  - → **organic matter type (source facies)**
  - → **level of maturity (thermal stress).**
- **Petroleum changes with production:**

  → **Production can lead to drop in pressure and change to a two phase system (liquid and gas) depending on fluid type and reservoir conditions. Two phase systems will yield higher volumes of gas relative to oil due to liquid drop out and relative permeability issues.**

- **In-situ petroleum composition has <u>significant</u> impact on production rates and ultimate hydrocarbon recovery thus want to optimize fluid system prediction to maximize liquids production.**

3.5 Hydrocarbon Storage





ORGANIC POROSITY

- Recent studies suggest organic porosity provide significant hydrocarbon storage potential in LRU systems.
- Organic porosity impacted by:
  - ✓ thermal maturity
  - ✓ organic matter type.
- ***Effective porosity*** requires connectivity within organic material as well as matrix (series or in parallel).
- Recent studies indicate OM connectivity is poor (Curtis et al., 2014).

☛ How can we better understand if organic porosity is a major contributor and if not, need to examine matrix for hydrocarbon storage.

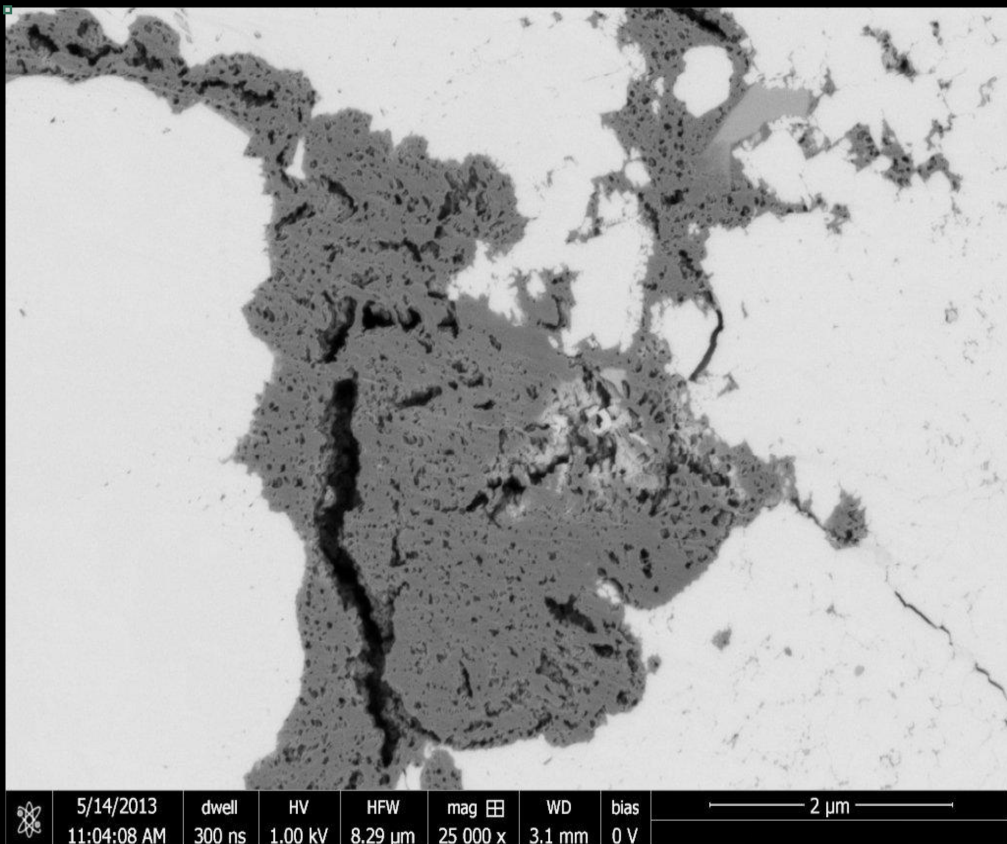
3.5 Hydrocarbon Storage, cont.

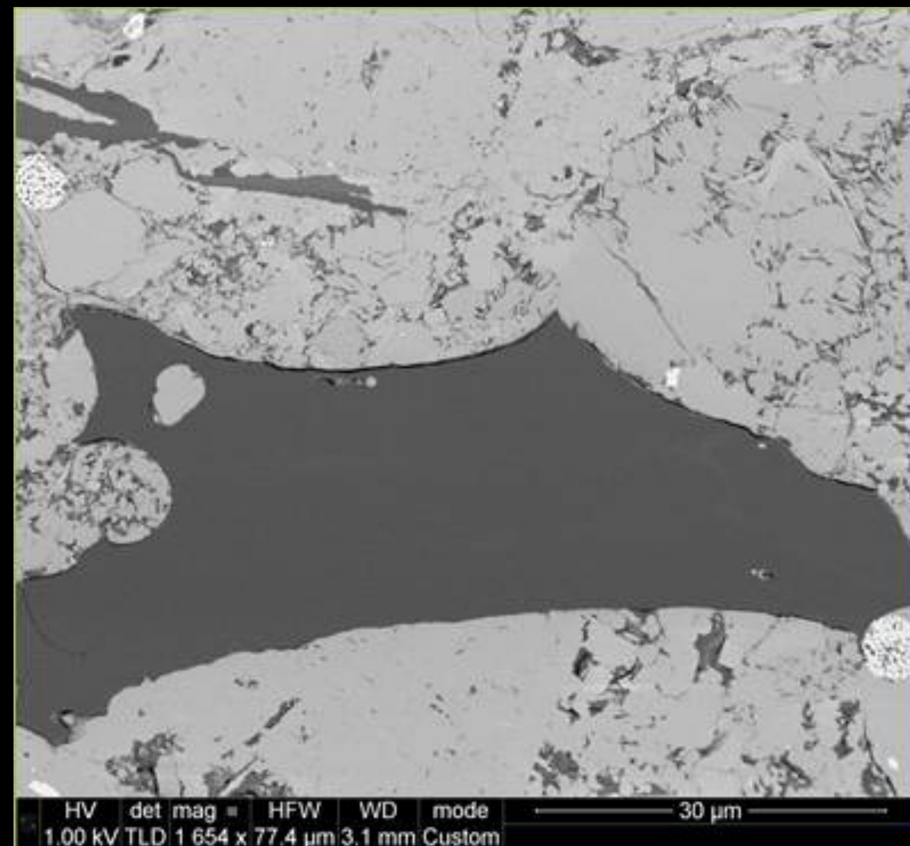
Basin A

Empirical observations indicate wells with enhanced organic porosity as seen via SEM, have higher production rates.

Basin B

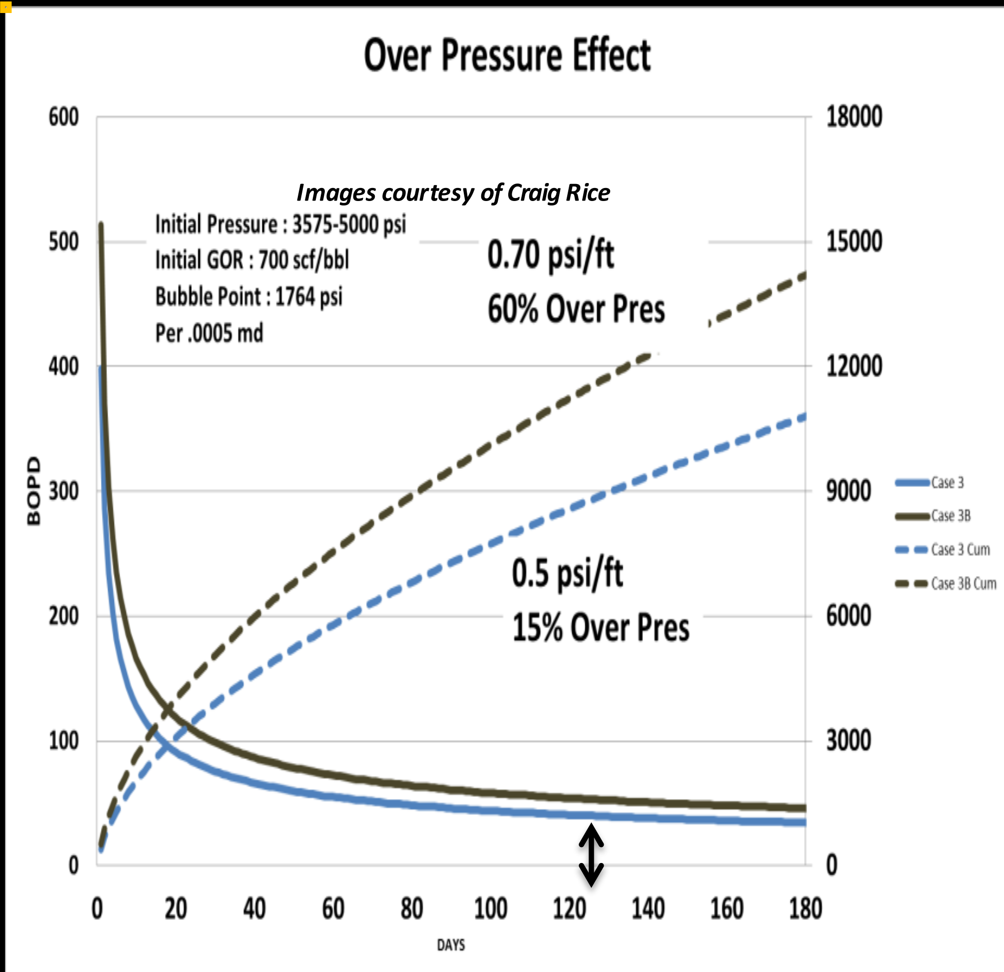
Liquid rich UCR core SEM images have little or no organic porosity, have very lower production rates.



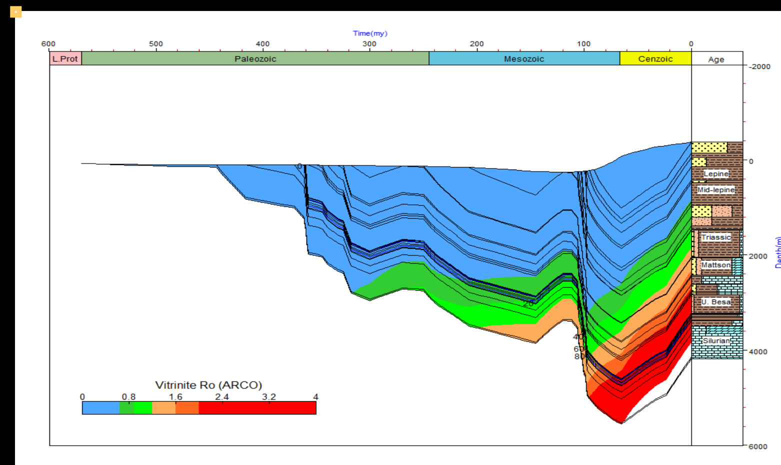


- Maturity is not significantly different between these two plays; impact of organic matter type and burial history on the formation organic porosity?

3.6 Flow Capacity



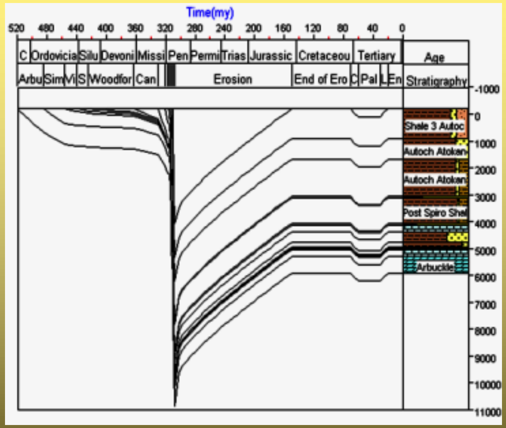
- *Porosity* and *permeability* play major role in reservoir flow capacity.
- *Pore pressure* is extremely critical (drive and phase)
- *Burial history* (burial rate) has significant impact on pore pressure as well as P&P.



☛ Fluid quality and flow capacity have major impact to "swing the needle" on economics.

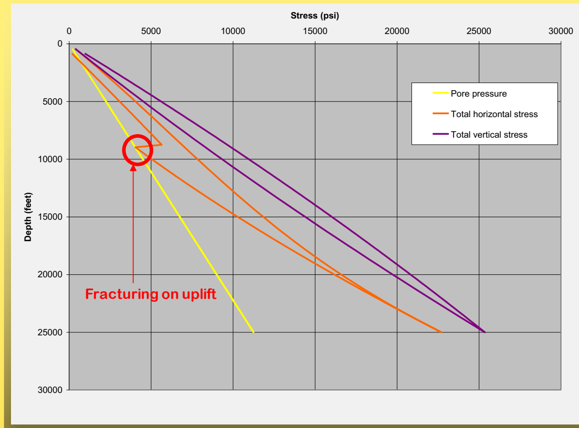
3.7 Rock Fracability

- ● ***Rock mineralogy***: major impact on brittleness (ductile versus brittle).
- ● ***Stress assessment***: regional structural regime (amount and direction).
- → ***Burial history***: maximum depth, burial rate, and potential uplift.

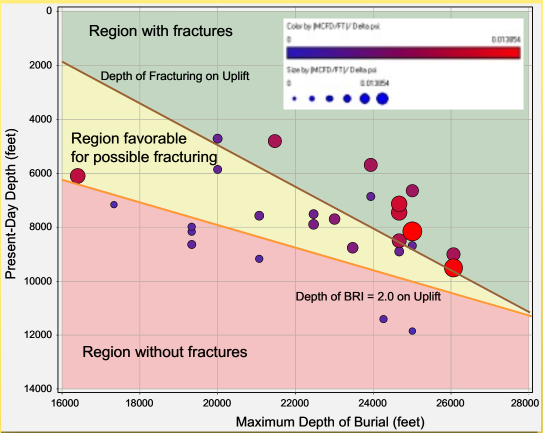


- Burial and exhumation history timing
- Thermal gradient
- Gross geologic setting
- Geomechanics properties (if available)

Image courtesy of Steve Wilson



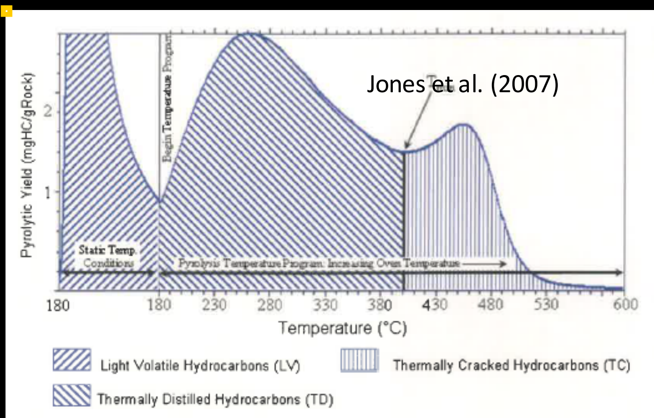
- Assessment of stresses ahead of drilling
- Identification of regions susceptible to fracturing
- Contributes to 'sweet spot' identification



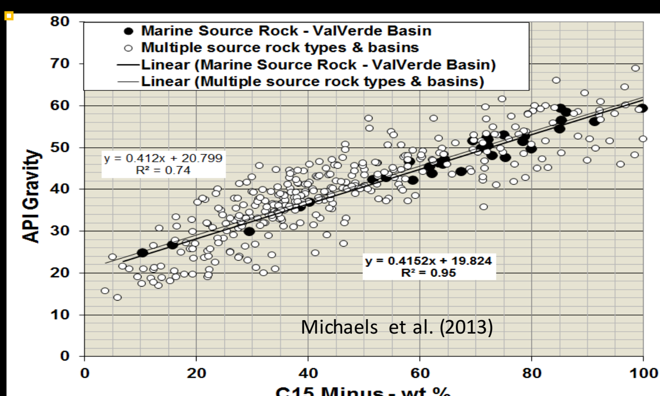
- Enhanced production occurs for optimal combinations of burial and exhumation
- Relatively simple screening tool for ranking access areas

4.0 Assessing *Oil in Place* and *Movable Oil*

- Two important measurements for evaluating LRU economics;
  - ✓ How much liquid hydrocarbon/non HC present (total volume in place oil)?
  - ✓ How much remaining oil is movable (producible with enhancement)?
- Current methodologies to evaluate *Oil-In-Place* (OIP):
  - ✓ Wireline log calculated petrophyiscal estimates.
  - ✓ Direct measurements from extracted hydrocarbon measurements.
- Both provide directional information on OIP but do not measure producible oil.



- *Pyrolytic Oil Productivity Index (POPI)* direct assessment of reservoir quality from residual staining on drill cuttings (Jones et al., 2007).
- Modified programmed pyrolysis to evaluate thermally distilled residual hydrocarbons.
  Light Volatiles – Thermally distilled – Thermally Cracked



- *Corrected S1 programmed pyrolysis* method by Michaels et al. (2013)* determine total resource in-place and calculate recovery factors.
- Developed work flow using standard programmed pyrolysis, applies correction factor to S1 (“free” hydrocarbons) to compensate for lost hydrocarbons.

* See presentation on Wednesday

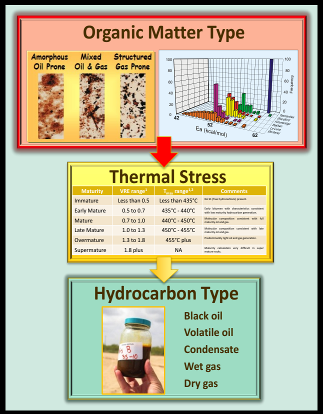
Petroleum System Charge Analysis for Liquid Rich Unconventional Plays

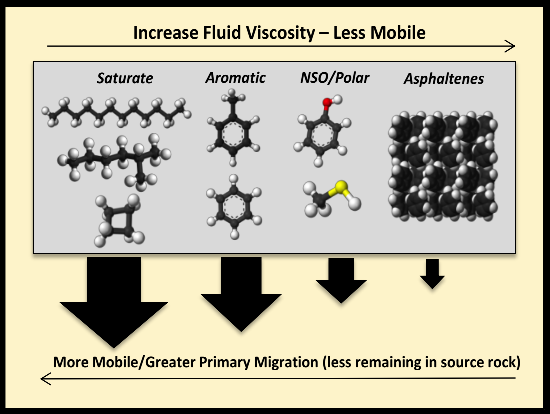
5.0 KEY TAKE AWAYS

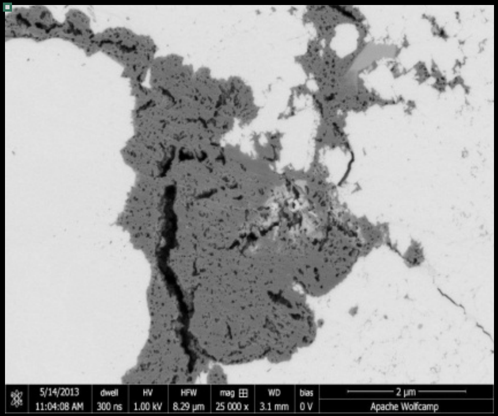
☛ Not all organic rich oil generating source rocks will provide an economic liquid-rich unconventional petroleum system.

Critical Petroleum Systems Elements:

- ✓ Regionally extensive and thick organic rich oil prone source rock (critical volume).
- ✓ Source rock with sufficient thermal maturity for given organic matter type to generate significant in-situ liquid rich volumes.
- ✓ Sufficient retained hydrocarbons after primary migration (expulsion efficiency).
- ✓ Optimal in-situ hydrocarbon fluid properties for host rock type (semi volatile oil).
- ✓ Significant in-place movable hydrocarbons for economic production rates/EUR.

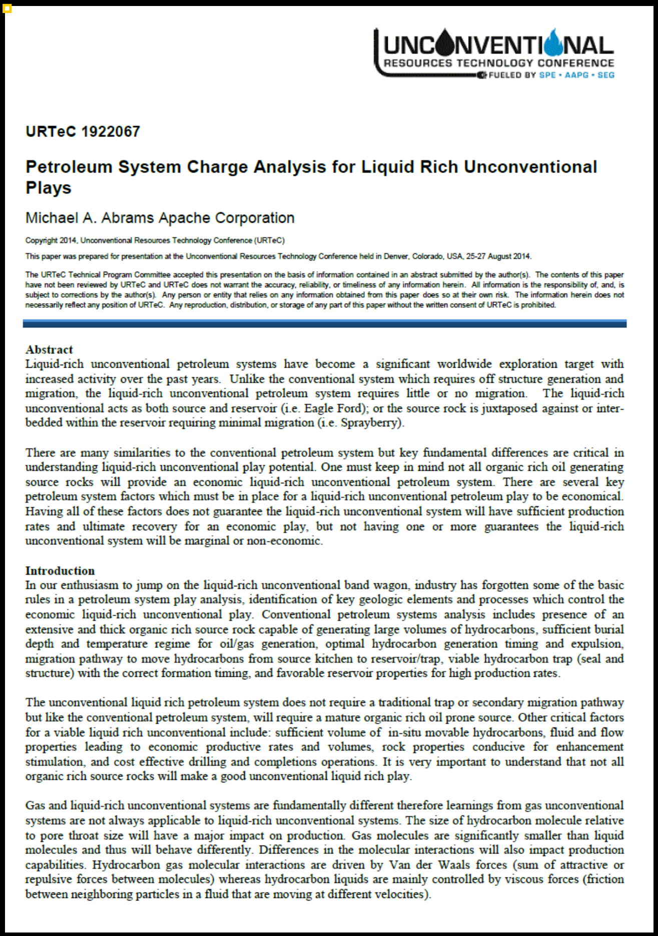






Petroleum System Charge Analysis for Liquid Rich Unconventional Plays
KEY TAKE AWAYS, cont.

Having critical petroleum systems factors in place does not guarantee your liquid-rich unconventional system will have sufficient *production rates* and *ultimate recovery* for an economic play, but not having one or more guarantees the liquid-rich unconventional system will be marginal or non-economic.



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Petroleum System Charge Analysis for Liquid Rich Unconventional Plays

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Abstract

Liquid-rich unconventional petroleum systems have become a significant worldwide exploration target with increased activity over the past years. Unlike the conventional system which requires off structure generation and migration, the liquid-rich unconventional petroleum system requires little or no migration. The liquid-rich unconventional acts as both source and reservoir (i.e. Eagle Ford); or the source rock is juxtaposed against or inter-bedded within the reservoir requiring minimal migration (i.e. Sprayberry).

There are many similarities to the conventional petroleum system but key fundamental differences are critical in understanding liquid-rich unconventional play potential. One must keep in mind not all organic rich oil generating source rocks will provide an economic liquid-rich unconventional petroleum system. There are several key petroleum system factors which must be in place for a liquid-rich unconventional petroleum play to be economical. Having all of these factors does not guarantee the liquid-rich unconventional system will have sufficient production rates and ultimate recovery for an economic play, but not having one or more guarantees the liquid-rich unconventional system will be marginal or non-economic.

Introduction

In our enthusiasm to jump on the liquid-rich unconventional band wagon, industry has forgotten some of the basic rules in a petroleum system play analysis, identification of key geologic elements and processes which control the economic liquid-rich unconventional play. Conventional petroleum systems analysis includes presence of an extensive and thick organic rich source rock capable of generating large volumes of hydrocarbons, sufficient burial depth and temperature regime for oil/gas generation, optimal hydrocarbon generation timing and expulsion, migration pathway to move hydrocarbons from source kitchen to reservoir/trap, viable hydrocarbon trap (seal and structure) with the correct formation timing, and favorable reservoir properties for high production rates.

The unconventional liquid rich petroleum system does not require a traditional trap or secondary migration pathway but like the conventional petroleum system, will require a mature organic rich oil prone source. Other critical factors for a viable liquid rich unconventional include: sufficient volume of in-situ movable hydrocarbons, fluid and flow properties leading to economic productive rates and volumes, rock properties conducive for enhancement stimulation, and cost effective drilling and completions operations. It is very important to understand that not all organic rich source rocks will make a good unconventional liquid rich play.

Gas and liquid-rich unconventional systems are fundamentally different therefore learnings from gas unconventional systems are not always applicable to liquid-rich unconventional systems. The size of hydrocarbon molecule relative to pore throat size will have a major impact on production. Gas molecules are significantly smaller than liquid molecules and thus will behave differently. Differences in the molecular interactions will also impact production capabilities. Hydrocarbon gas molecular interactions are driven by Van der Waals forces (sum of attractive or repulsive forces between molecules) whereas hydrocarbon liquids are mainly controlled by viscous forces (friction between neighboring particles in a fluid that are moving at different velocities).

Future research needs:

- ✓ Measurement of in situ organic maturity.
- ✓ More quantitative evaluation OMT.
- ✓ Better understanding retained hydrocarbons and in-situ organic-matrix interactions.
- ✓ Significance organic porosity in LRU plays.
- ✓ Measure producible hydrocarbons vs OIP.

Acknowledgments

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