Application of PVT and Petroleum Geochemical Analyses to Enhanced Oil Recovery of Tight Sands

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Introduction

- "Huff and Puff" – cyclic gas injection Enhanced Oil Recovery (EOR). Unlike conventional gas injection EOR with an Injector and a Producer

- Ideally gas is miscibly injected, dissolving in the oil causing swelling and reduced viscosity

- PVT properties and phase behavior (and estimations of those from geochemical analyses) are key drivers

- Presentation follows a typical laboratory program

  Geochemistry (Stable Carbon Isotopes) -> PVT Analyses -> EOR Testing

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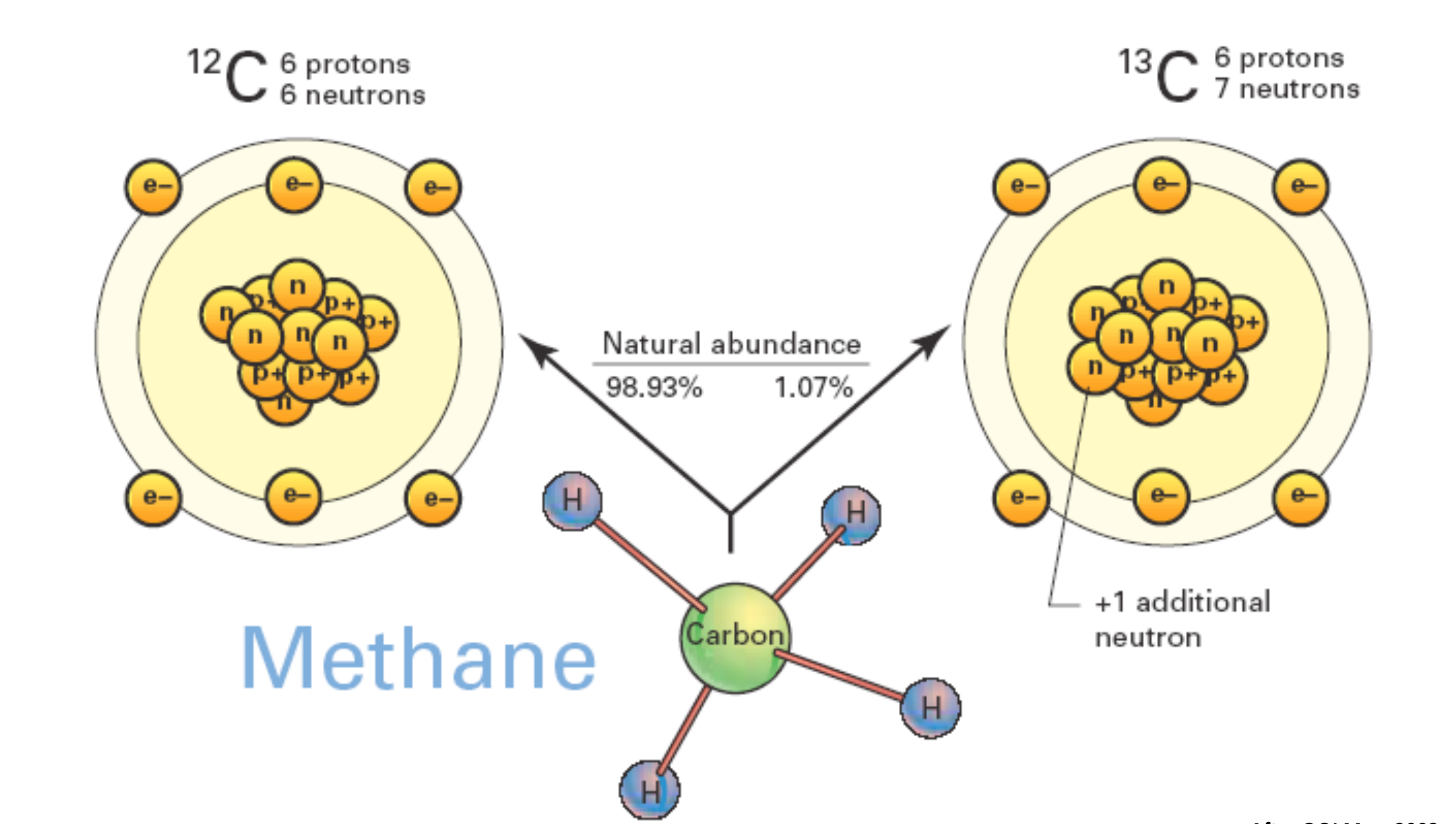
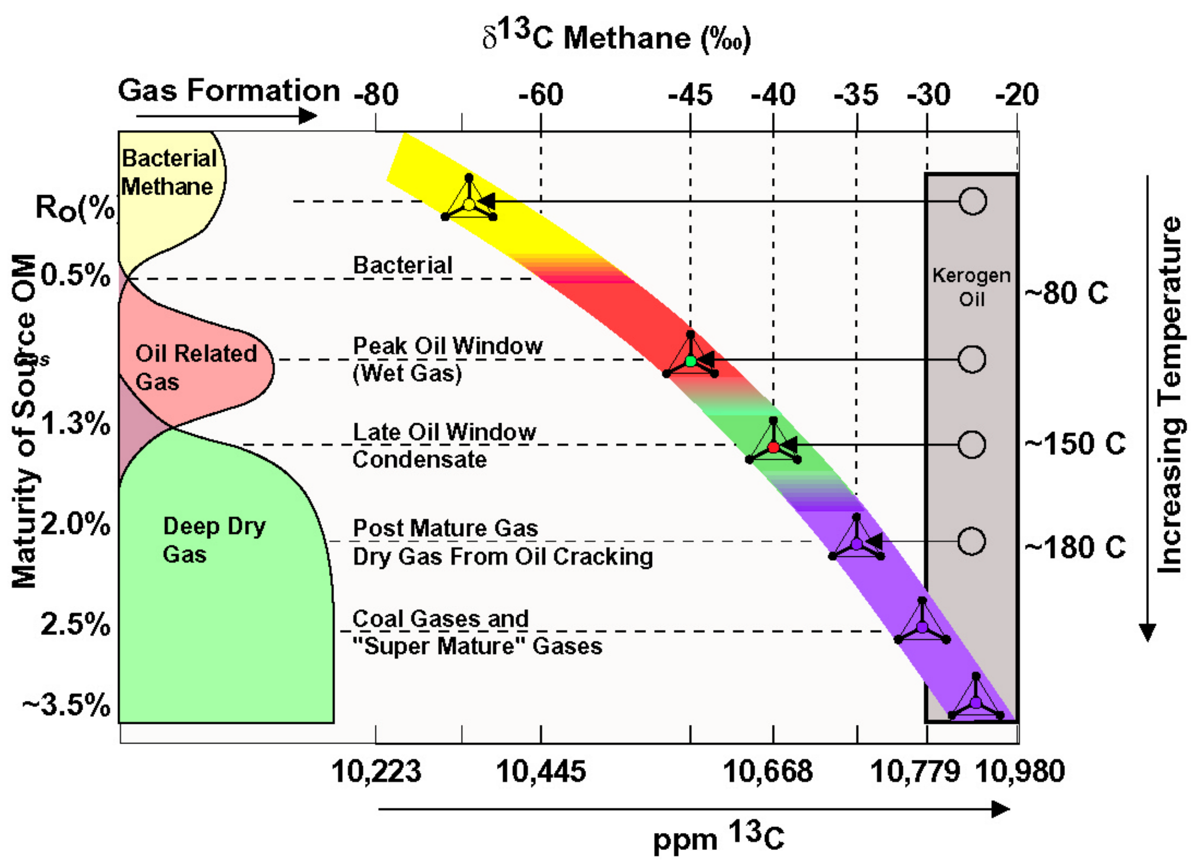
Stable Carbon Isotopes



After OGJ May, 2003

C1 Isotopes Related to Oil and Gas Formation



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Oil Quality Influences in Shale Plays

- Source Rock Type
  - Marine Shales
  - Marine Carbonates
  - Lacustrine Shales
- Thermal History of Source Rock
  - Depth of Burial
  - Timing of Generation
- Post Generative Alteration
  - Biodegradation
- Reservoir Mixing
  - Multiple Sources
  - Biogenic Methane

Phase Changes
Bubble and Dew Points

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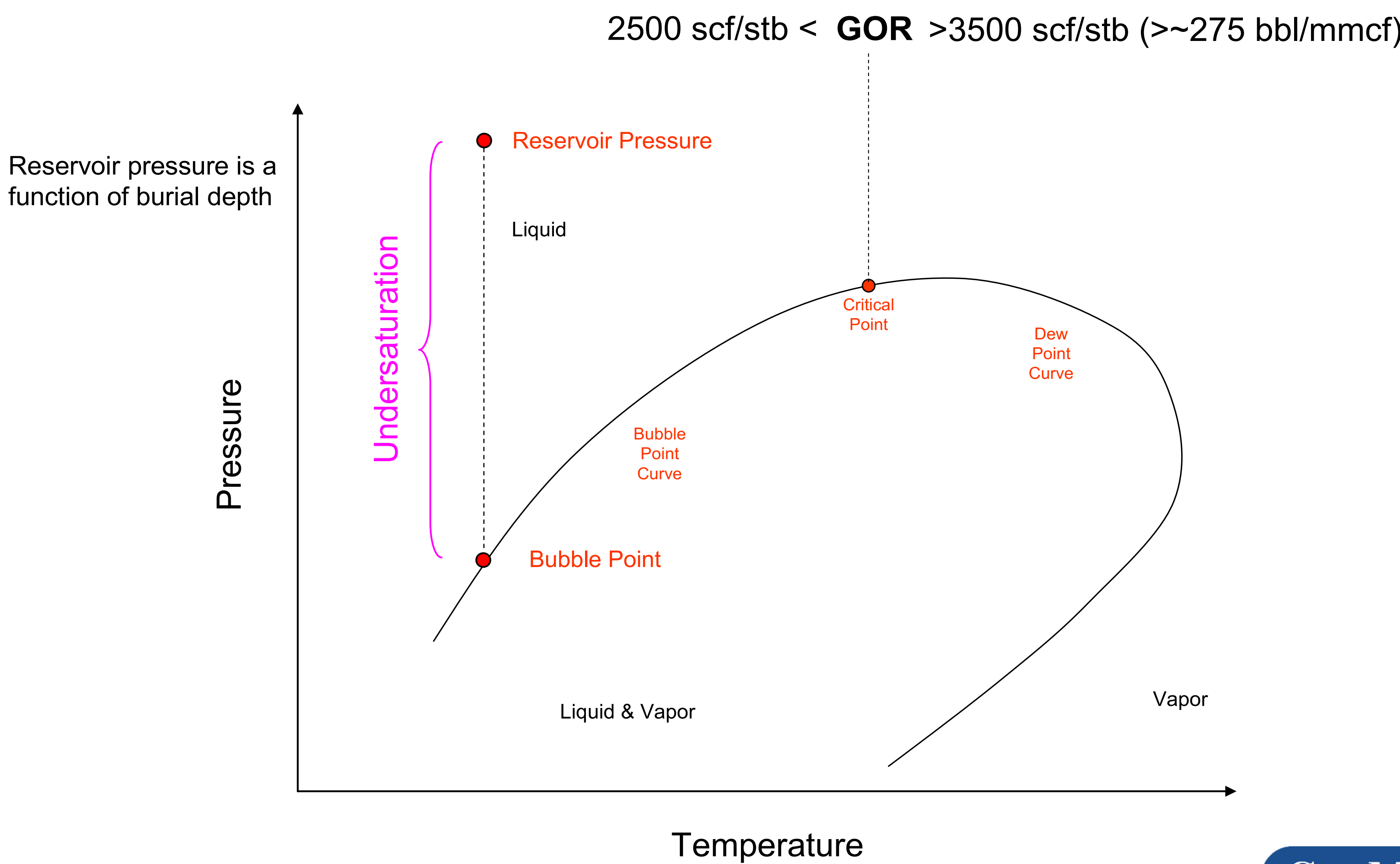
Fluid Properties and Phase Behavior Definitions

- Live vs. Dead Oil
- Single-Stage Flash (SSF)
- GOR (Rs, scf/stb) or Yield (bbl/mmscf)
- API Gravity (°API)
- Formation Volume Factor (Bo)
- Viscosity (cP)
- Saturation Pressure (Psat) (Bubble and Dew Points)
- Mud Content (wt% STO)
- Flow Assurance (solids precipitation)

Example Phase Envelope



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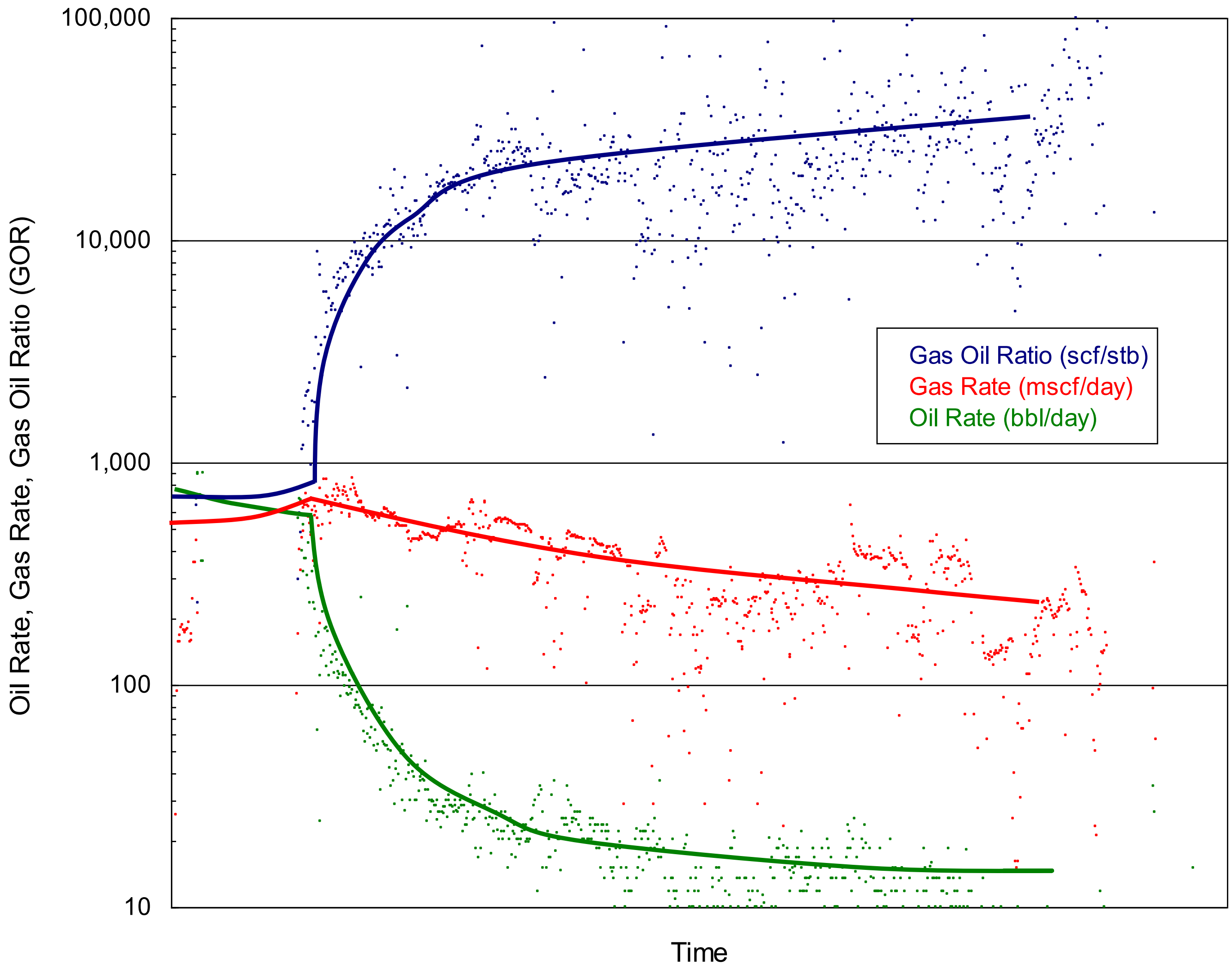
Shale Oil Production – Below Bubble Point

“Time to Saturation” is greatest oil production

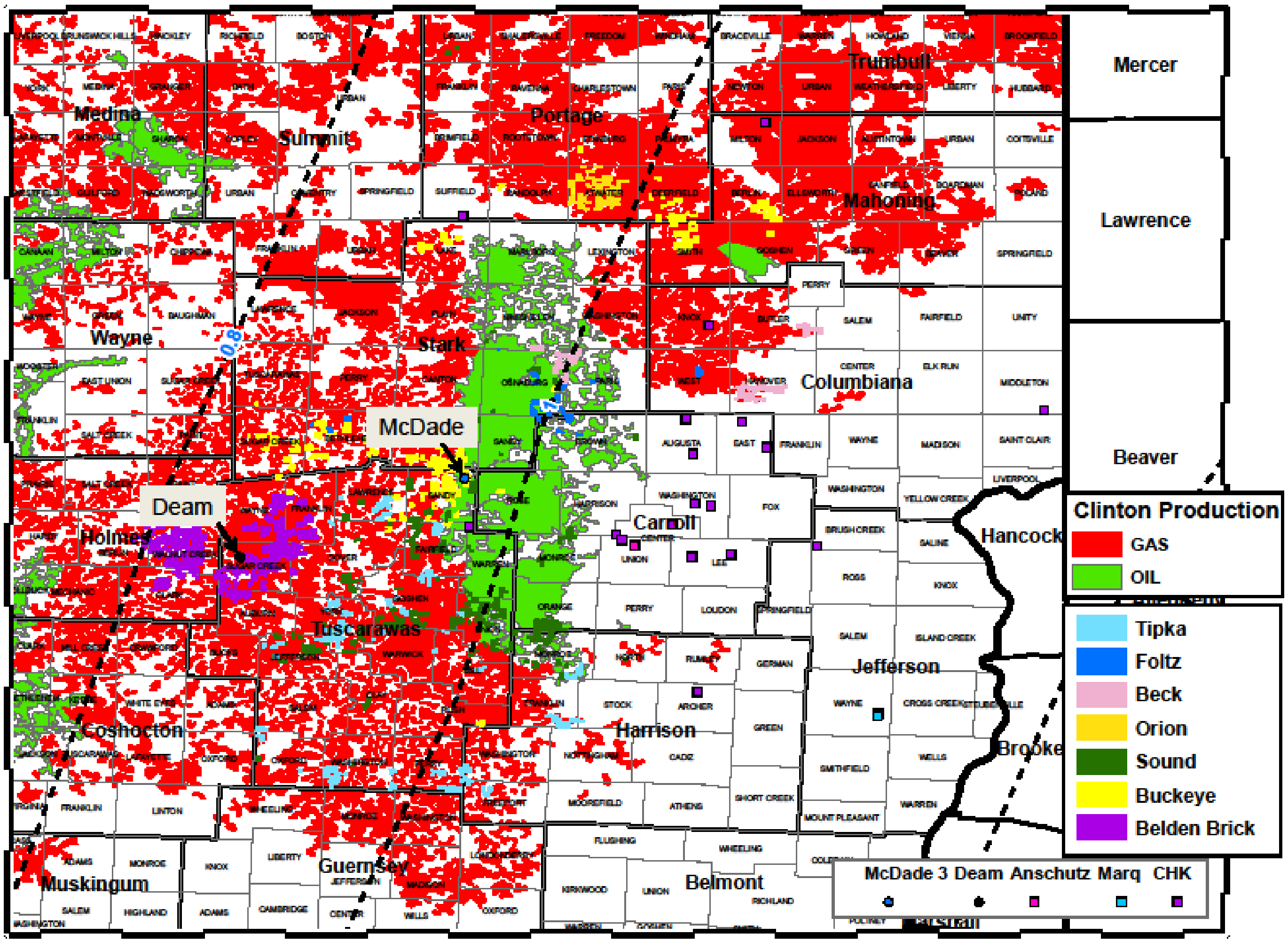
1. Reservoir Pressure vs. Saturation Pressure

2. Pressure decline depending on production rate

3. Size of fracture matrix relating to pressure drawdown



Utica Shale Map – Eastern Ohio
"Clinton" Historical Production



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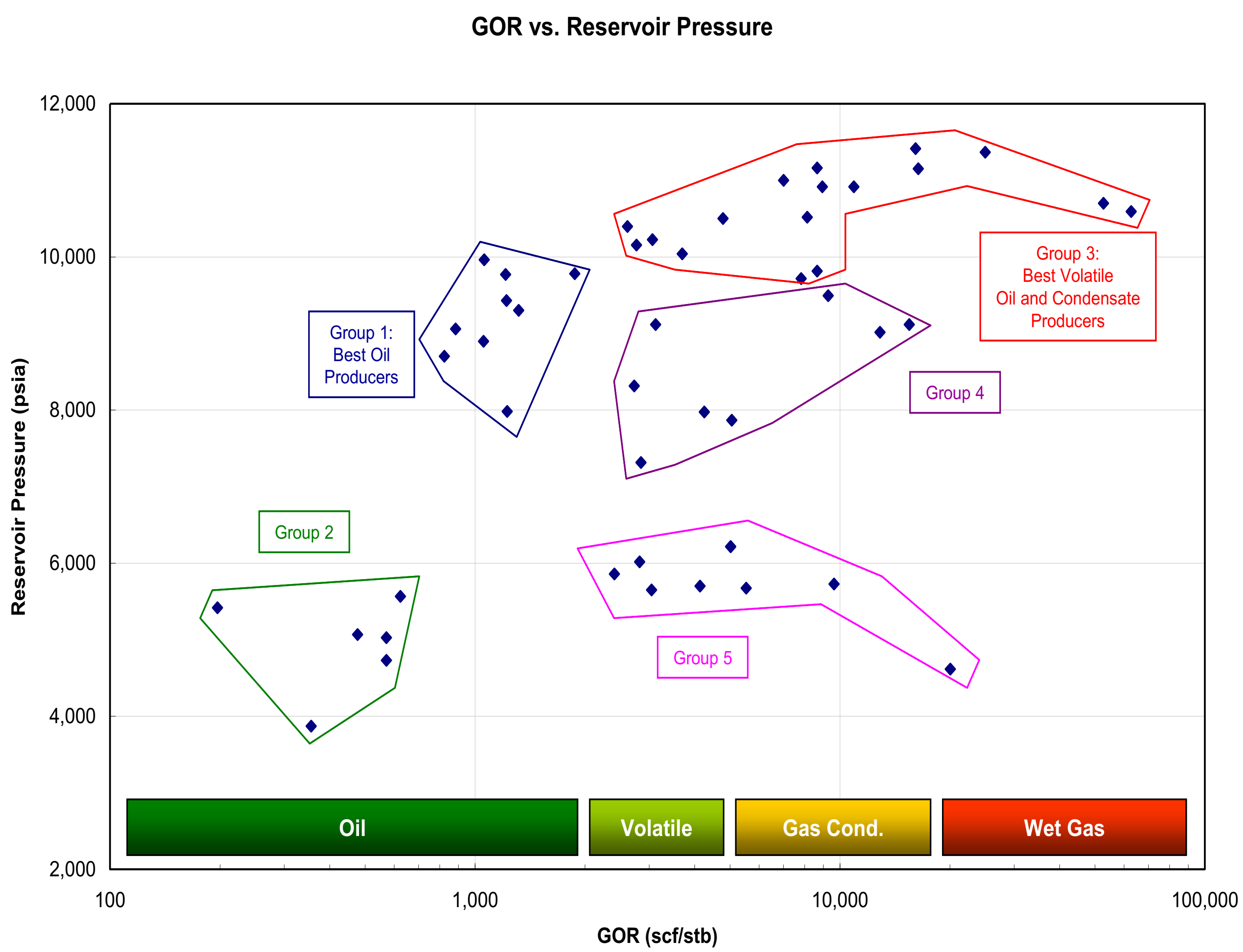
Eagle Ford GOR vs. Reservoir Pressure



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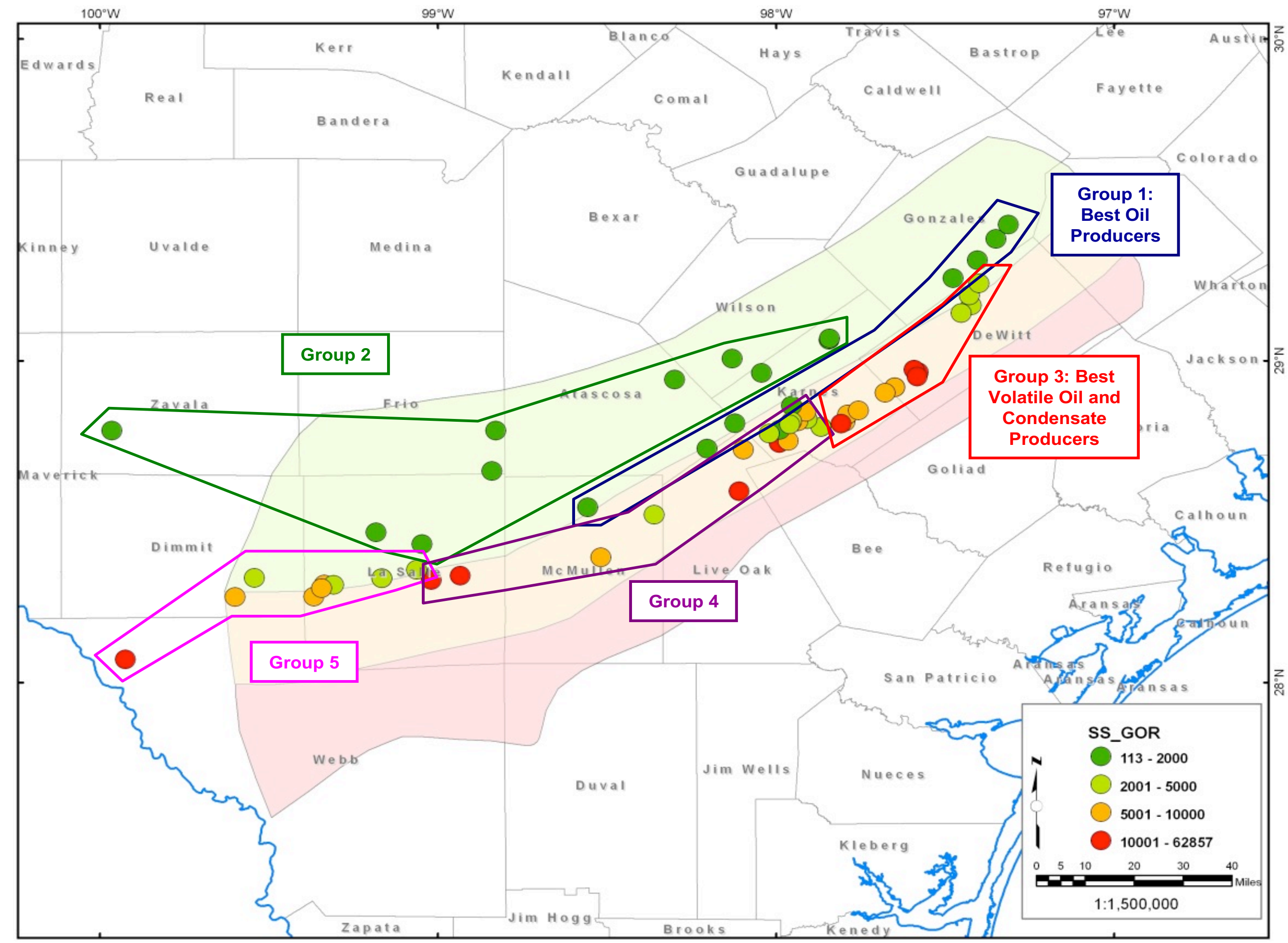
Eagle Ford GOR Map



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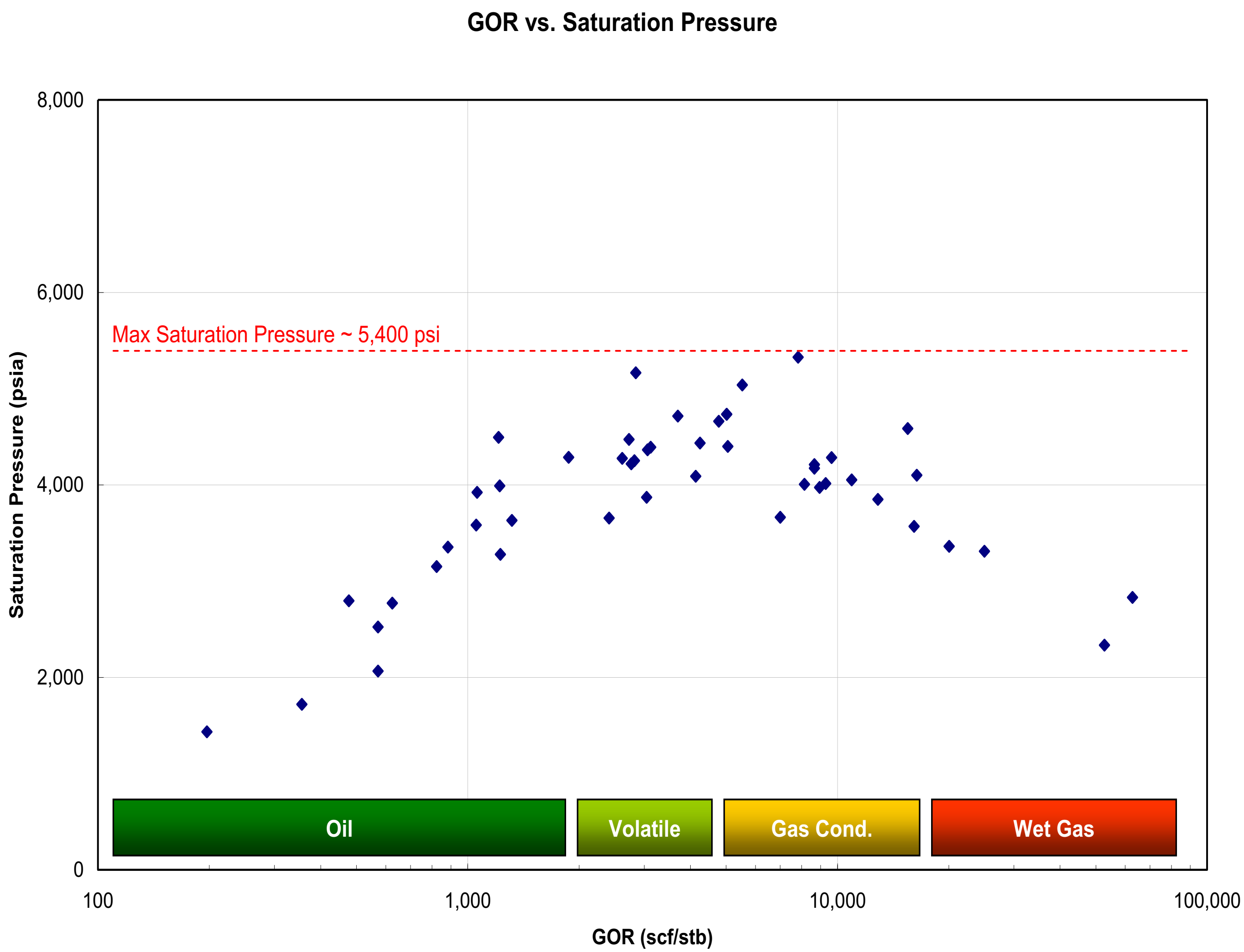
Eagle Ford GOR vs. Saturation Pressure



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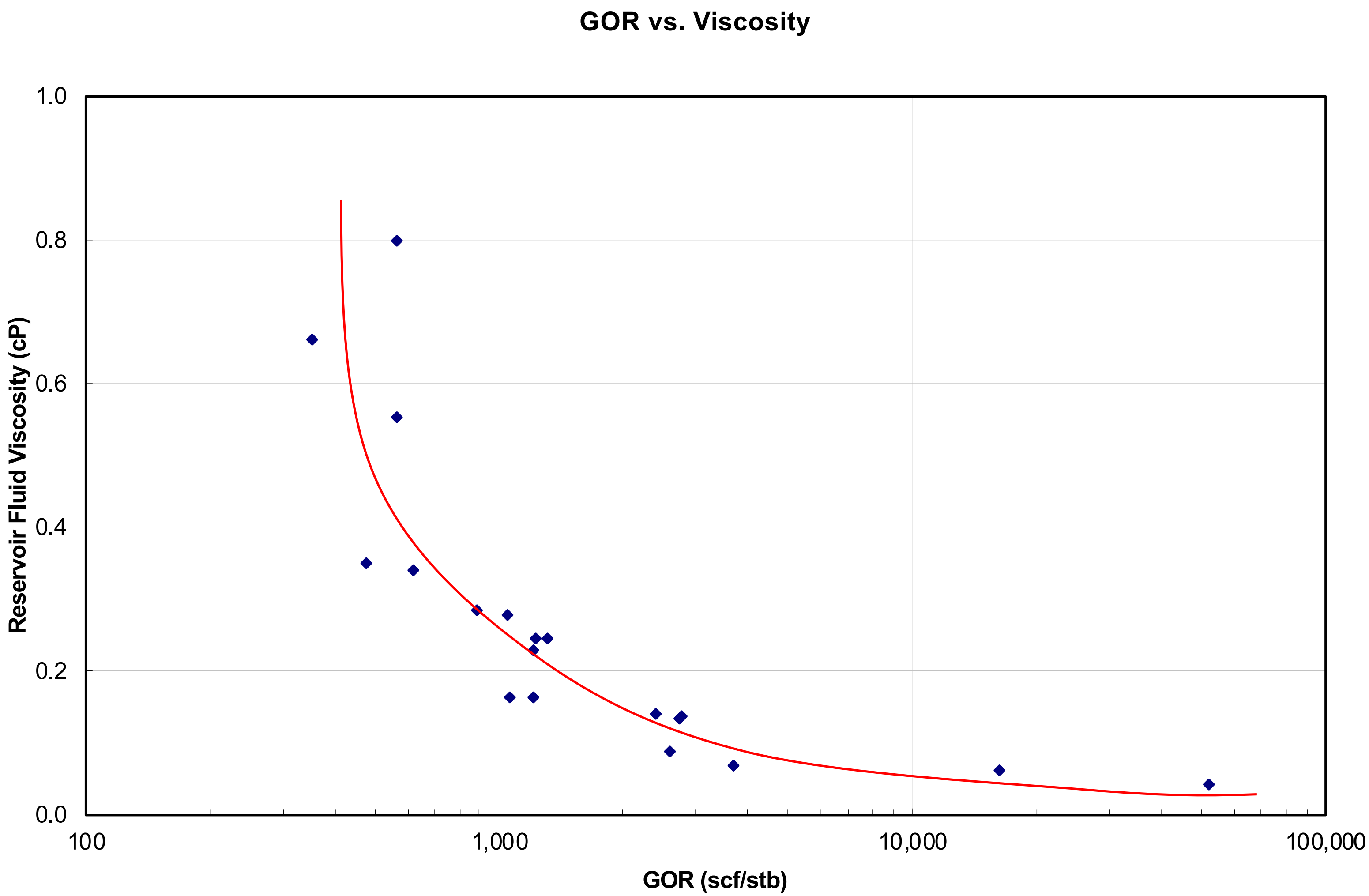
Eagle Ford GOR vs. Viscosity



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“Huff and Puff” Fluid Laboratory Studies

- Traditional PVT
  - Separator Sample Collection and Recombination
  - Constant Composition Expansion (Bubble Point Pressure)
  - Differential Liberation and Separator Test
  - Viscosities

- Swelling / Vaporization
  - Swelling Test if Reservoir Pressure >> Bubble Point
  - Vaporization (Multi-Contact) if Reservoir Pressure ~ Bubble Point

- Slim Tube
  - Best method for getting minimum miscibility pressure (MMP)
  - Recreates “mixing front” as increasingly heavy gas contacts increasingly light oil

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"Huff and Puff" Lab Results – Eagle Ford Example

- ~ 1,000 GOR Oil – 45°API
- Reservoir Pressure = 5,600 psi @ 230°F. Bubble Point = 3,200 psi
- Reservoir Fluid Viscosity = 0.36 cP

- Rich Injection Gas
  - 72 mole % Methane - 1,225 BTU
  - Rich injection gas should dissolve in oil easier (like dissolves like)

- Synthetic Dry Injection Gas
  - 90 mole % Methane – 990 BTU
  - Economics improved if liquids can be stripped and sold before reinjection

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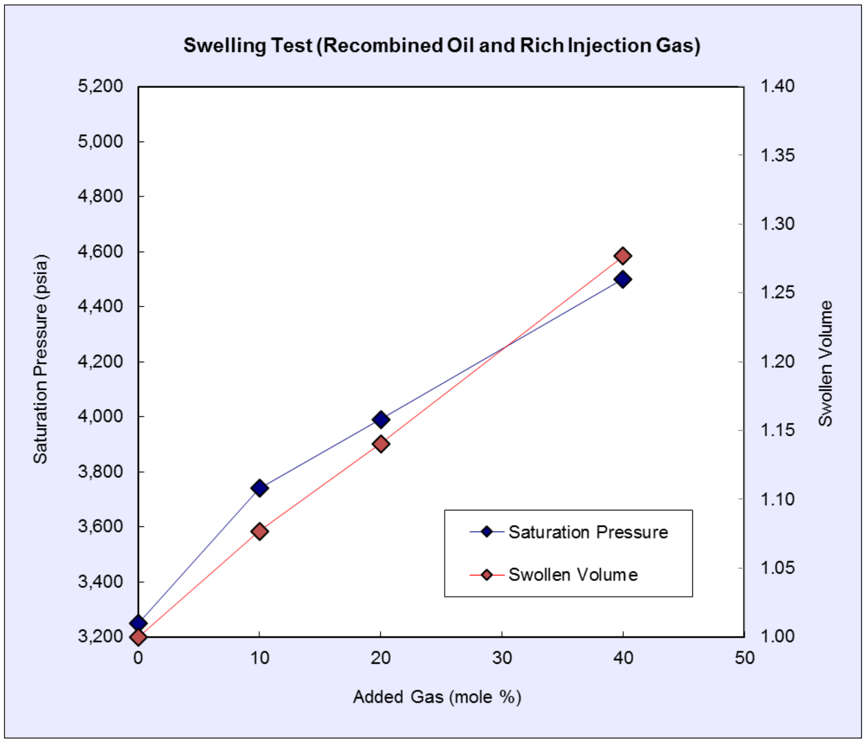
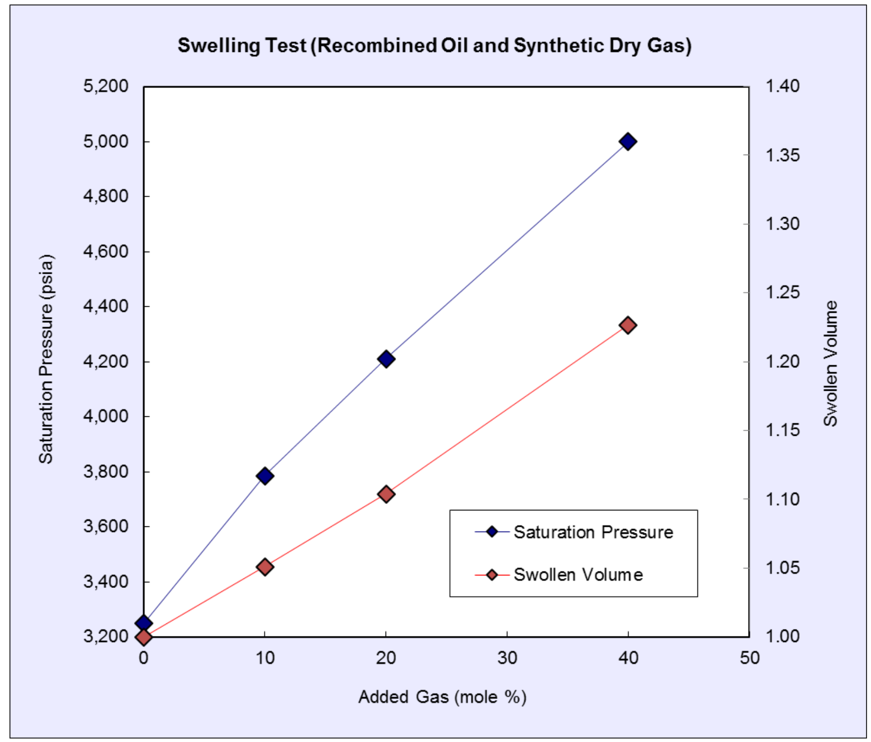
Swelling Test – Eagle Ford Example

Rich Injection Gas

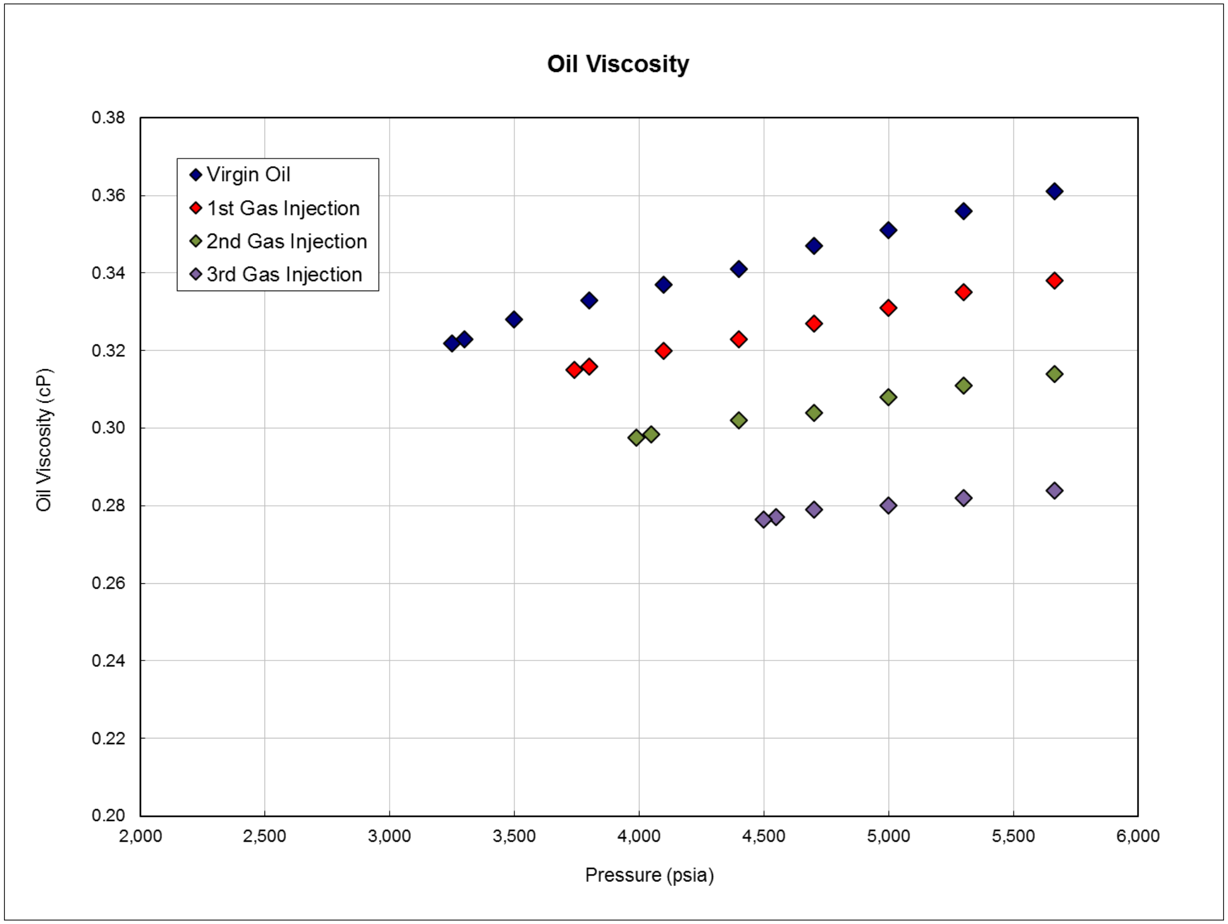


Synthetic Dry Gas

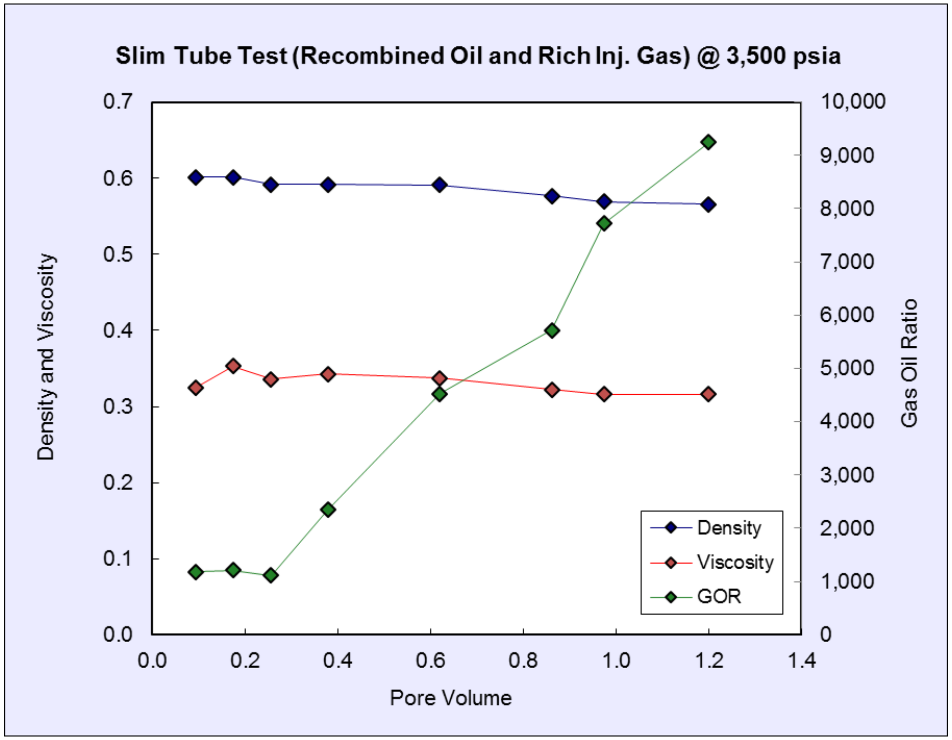


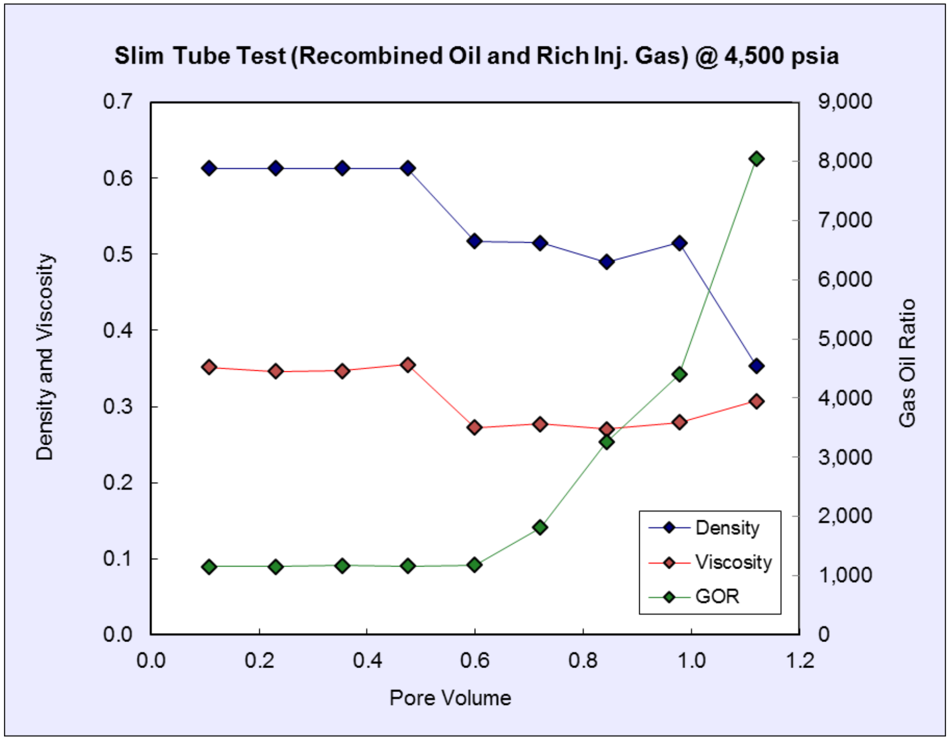
Swelling Test – Eagle Ford Example

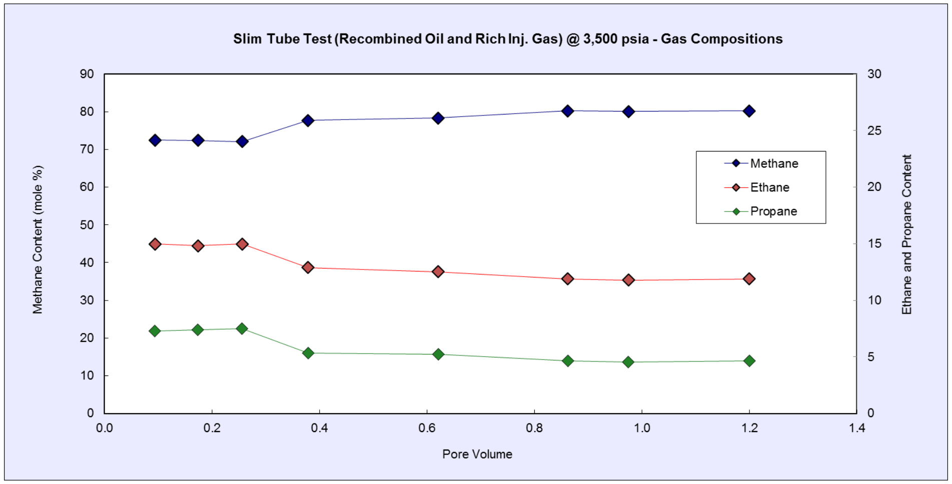
Rich Injection Gas

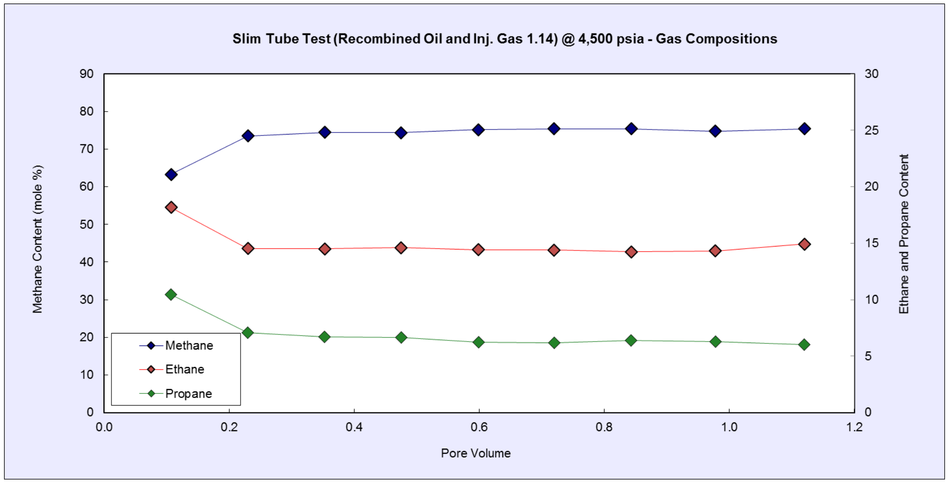


Slim Tube Test – Eagle Ford Example



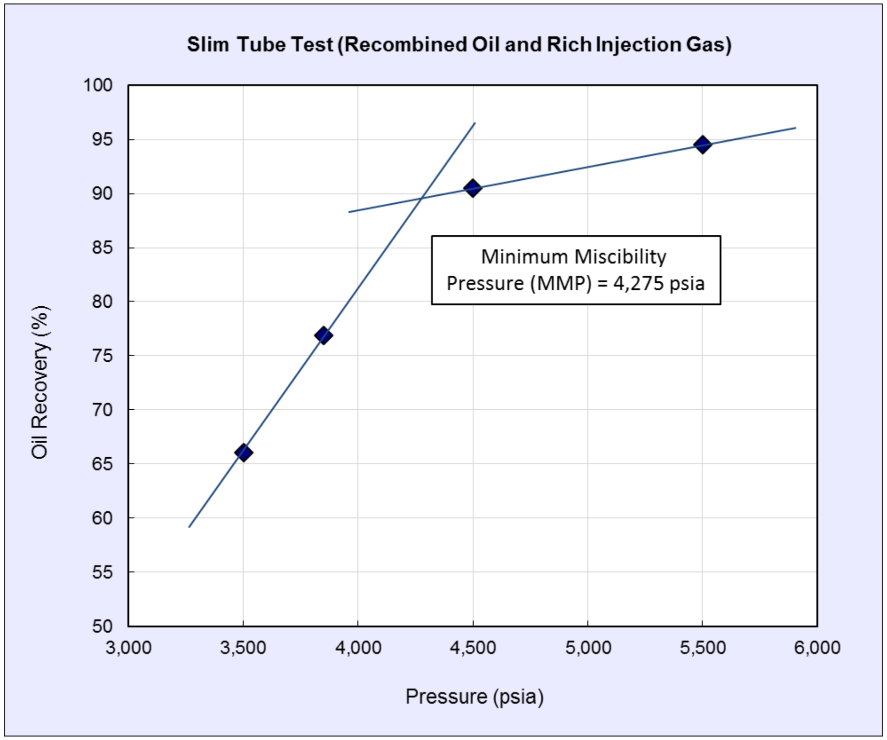




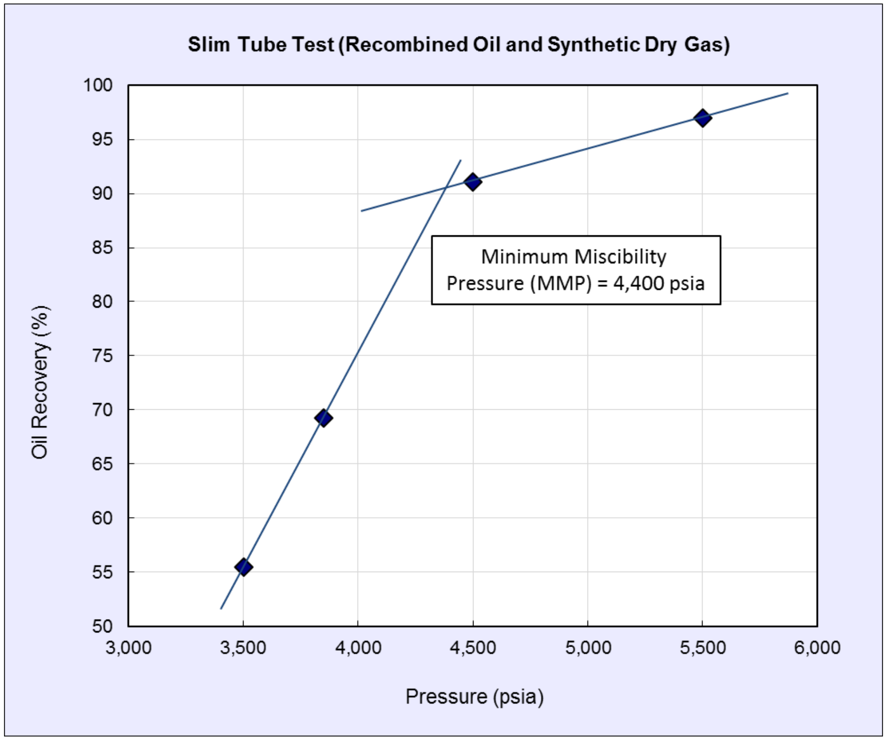


Slim Tube Test – Eagle Ford Example

Rich Injection Gas



Synthetic Dry Gas



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Multi-Contact Vaporization Test Example

Low GOR oil from the Permian

1st Contact

Component Name	Res. Fluid (mole %)	Injection Gas (mole %)	1st Contact Vapor (mole %)	1st Contact Oil (mole %)
N2	0.05	0.77	0.92	0.24
CO2	0.06	0.11	0.11	0.07
H2S	0.00	0.00	0.00	0.00
C1	19.25	75.82	77.92	35.44
C2	8.72	12.66	11.06	10.12
C3	7.72	6.28	4.94	7.48
iC4	1.50	0.84	0.64	1.34
nC4	4.70	1.94	1.62	3.94
iC5	1.89	0.39	0.42	1.45
nC5	2.74	0.50	0.55	2.08

Bubble Point 1,000 psi (Res. Fluid)

Bubble Point 2,550 psi (1st Contact Oil)

2nd Contact

Component Name	2nd Contact Vapor (mole %)	2nd Contact Oil (mole %)
N2	0.82	0.22
CO2	0.11	0.07
H2S	0.00	0.00
C1	76.81	35.31
C2	11.71	10.71
C3	5.40	8.01
iC4	0.69	1.42
nC4	1.70	4.06
iC5	0.42	1.42
nC5	0.55	2.04

3rd Contact

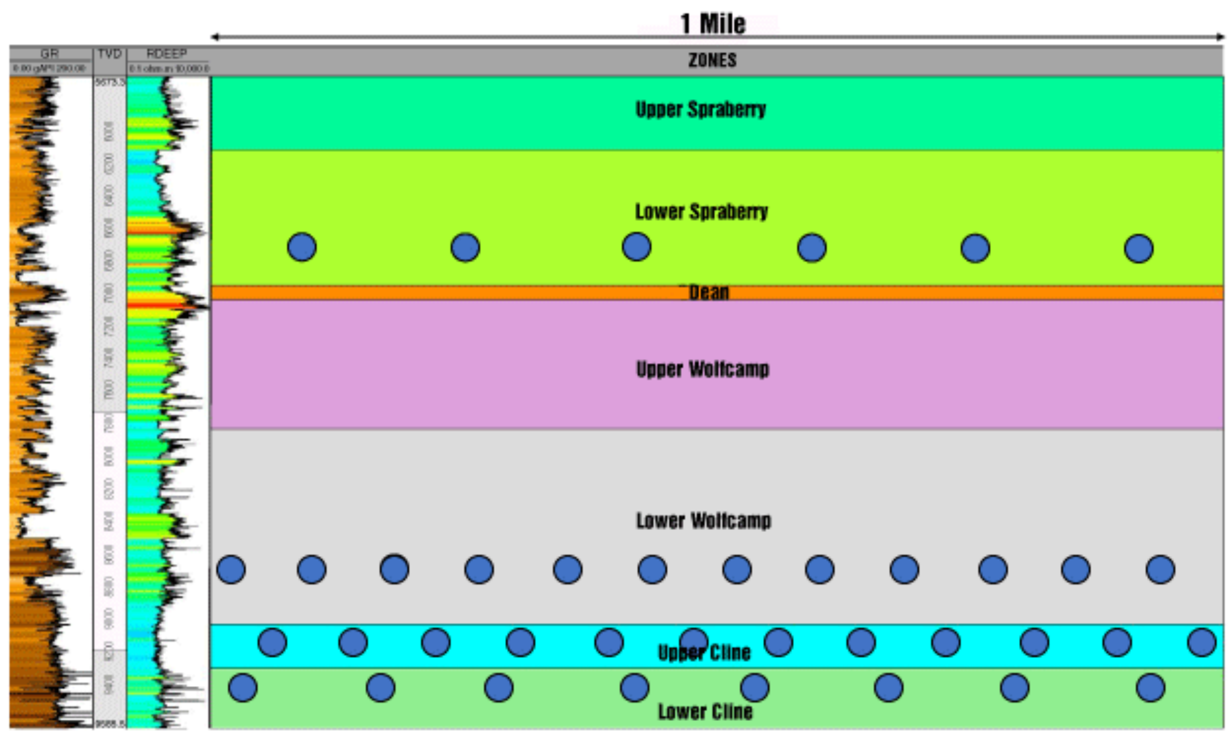
Component Name	3rd Contact Vapor (mole %)	3rd Contact Oil (mole %)
N2	0.77	0.21
CO2	0.11	0.07
H2S	0.00	0.00
C1	75.72	34.99
C2	12.29	11.22
C3	5.86	8.63
iC4	0.76	1.55
nC4	1.81	4.28
iC5	0.42	1.40
nC5	0.55	2.00

Bubble Point 3,480 psi (2nd Contact Oil)

Bubble Point 4,350 psi (3rd Contact Oil)

Huff and Puff + Time Lapse Geochemistry

- Time-Lapse Geochemistry is used to evaluate possible communication between different units and formations in unconventional plays.
- Similar technology is used to "follow the injection gas" and evaluate the effectiveness of the injection



https://www.aogr.com/web-exclusives/exclusive-story/approach-optimizes-midland-basin-development

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Conclusions

- Early Huff and Puff pilots and operations generally look promising
- Fluid and Rock Properties are important
  - Reservoir pressure vs. Bubble Point (from PVT and/or geochemistry)
  - Rock mechanics / fractures for gas containment
  - Injection gas availability and properties
- Key variables include
  - Injection gas types, rates, times
  - When to start cycles, how many
- Technical challenges addressed -> Economics

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