Finding Sweet Spots in Shale Liquids and Gas Plays:  
(with Lessons from the Eagle Ford Shale)*

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Editor’s note: This article is also an adaptation from an earlier presentation at AAPG ACE, April 22-25, 2012, on the general subject by the author. Adaptation of the earlier presentation, entitled “Sweet Spots in Shale Gas and Liquids Plays: Prediction of Fluid Composition and Reservoir Pressure” is Search and Discovery Article #40936 (2012) (http://www.searchanddiscovery.com/documents/2012/40936cander/ndx_cander.pdf).  

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Abstract

This article discusses the importance of understanding petroleum composition (Gas-Oil ratio and viscosity) and reservoir pressure in order to find sweet spots in shale liquids plays. This study also demonstrates the importance of understanding post-burial uplift in shale plays. Although most companies focus on finding the right rock (using TOC, thickness, brittleness, etc.) the properties of reservoir fluids and pressure are at least as important as properties of the rock for defining the most valuable parts of a shale fairway. This study shows that the sweet spot (i.e., the most profitable part) of the Eagle Ford Shale is found where the least viscous liquid phase and the most oil-rich vapor phase occur at highest reservoir pressure.

For this study, in-house source-rock kinetic models were coupled with regional basin modeling in the Eagle Ford Shale fairway to delineate the sweet spot. This work involved the prediction of petroleum compositions and evaluation of the effect of petroleum generation on pore pressure. Maps of thermal stress were converted to maps of gas-oil ratio, viscosity, and BTU content to predict mobility of shale liquids and flow of revenue from wells across the fairway. The results of this study indicate that petroleum compositions in the Eagle Ford Shale are closer to an instantaneous product over a narrow thermal stress range rather than a cumulative product from expulsion and migration over a broad range of thermal stress. The petroleum is in near equilibrium with the thermal stress state of the rock, and most petroleum was generated in situ and retained as the last generated product with limited lateral migration. Fluid viscosities are closely linked to composition (GOR) and are, therefore, predictable. Thus, although the Eagle Ford expelled large volumes of petroleum and this petroleum migrated out of the formation, the petroleum that we produce from the Eagle Ford was generated in situ and is not the result of lateral migration.
Mobility of shale liquids and, thus, revenue flow are also strongly a function of reservoir pressure. The reservoir pressure we see in the Eagle Ford today is the result of how the pressure was created and how it was preserved after burial. Several authors have proposed that most of the over-pressure in shale source rocks was created by petroleum generation. Basin modeling performed in this study suggests that petroleum generation can account for some of the over-pressure within the Eagle Ford Shale gas and liquids fairway (as measured in psi above hydrostatic). However, much of the regional over-pressure was generated from disequilibrium compaction during rapid Late Cretaceous through Paleogene burial. Late exhumation altered shale reservoir pore pressure in the western half of the Eagle Ford fairway. The central part of the Eagle Ford fairway had comparatively less uplift. As a result, the amount of over-pressure in the western part of the fairway is not directly linked to thermal maturity and GOR. Fluids with higher Gas-Oil ratio occur at relatively lower reservoir pressure in the west compared to the central part of the fairway. Therefore, whereas retained petroleum properties can be linked closely to thermal stress, creation and retention of over-pressure is not strictly due to petroleum generation and a broader, basin-scale interpretation is required in order to define regions where revenue generation will be highest. Because it is often the foreland phase of rapid subsidence and burial that catalyzes both disequilibrium compaction and source-rock maturation, the generation of petroleum and over-pressure are often coeval, and their effects on reservoir pressure, effective stress, permeability, and reservoir deliverability can be difficult to differentiate. Lastly, it can be shown that there is a strong inverse link between uplift and over-pressure. North American onshore basins that have experienced large amounts of uplift and erosion are often normally pressured. Basins that have experienced minor amounts of uplift and erosion have retained high over-pressure.

References Cited


Momper, J.A., 1979, Domestic oil reserves forecasting method, regional potential assessment: Oil and Gas Journal, v. 77/33, p. 144-149.
Finding Sweet Spots in Shale Liquids and Gas Plays

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What is this talk about?

- Identify sweet spots with very little data
- Sweet spot = Highest IRR
- Greatest mobility of most valuable fluid

*Mobility* of fluids in tight rock
  - Fluid viscosity
  - Reservoir pressure
Petroleum & GOR

- Petroleum is a mixture of gas and oil

- Gas  C1 – C5

- Oil  C6+

- Gas-Oil Ratio (GOR)
  - Ratio of  C1-C5  to  C6+  scf/bbl
<table>
<thead>
<tr>
<th>Type</th>
<th>Gas Oil Ratio (scf/bbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High viscosity Oil</td>
<td>&lt; 200</td>
</tr>
<tr>
<td>Black oil</td>
<td>200 - 1000</td>
</tr>
<tr>
<td>Volatile oil</td>
<td>1000 - 3200</td>
</tr>
<tr>
<td>Wet Gas / Condensate</td>
<td>3200 – 15,000</td>
</tr>
<tr>
<td>Wet Gas</td>
<td>15,000 – 70,000</td>
</tr>
<tr>
<td>Dry Gas</td>
<td>&gt; 70,000</td>
</tr>
</tbody>
</table>
Phase

Liquid  < 3200  GOR

Vapor  > 3200  GOR

Liquid can contain a lot of C1-5
Vapor can contain a lot of C6+
What are “unconventionals”?

Cander, H., 2012, AAPG Search and Discovery # 80217

- Oil shales
- Heavy oil
- Low GOR shale oil
- Onshore viscous oil
- Shale & Tight oil
- GOM Neogene oil fields
- Shale wet gas
- Trinidad offshore gas fields
- Shale dry gas
- Tight gas

Viscosity (μ) vs. Permeability (k) chart.
Eagle Ford Fluid Fairways

Sweet spot

OIL

Wet gas

Dry gas

EOG Leases

0 25 Miles
Eagle Ford liquids sweet spot
Intersection of GOR and High Pressure

Reservoir Pressure  psi

3200 GOR Liquid Vapor

SWEET SPOT

10,000 psi

H. Cander 2013
Liquids Sweet Spot
Least viscous liquid phase at highest pressure
Most liquids-rich vapor phase at highest pressure

Predicted GOR scf/bbl
With 10,000 psi line
“Unconventional” but still obey principles

\[ Q = \frac{k \times H \times DP}{m} \]

- \( Q \) = well flow rate
- \( k \) = permeability
- \( H \) = thickness
- \( DP \) = Reservoir Pressure – wellbore pressure
- \( m \) = viscosity

\( P \) and \( m \) change a lot in a typical shale fairway!
Maturity vs. GOR & Viscosity

Temperature C

GOR (scf/bbl)

Viscosity (cp)
Eagle Ford Gas Rate

Influence of viscosity – even in “gas”

GOR
scf/bbl

Vapor
Liquid

Rate  mcfd

IHS data
IP30 MCFD vs. GOR

GOR  Scf/bbl

Vapor

Liquid

Rate MCFD  IP30
Liquids Rate (IP30 BOPD) vs. GOR
Data from mid-2011

GOR (scf/bbl)

Composition Effect

Viscosity Effect

Vapor

Liquid
IP30 BOPD vs. GOR

GOR
Scf/bbl

Rate BOPD IP30
Oil Rate (IP30 BOPD) vs. GOR
Karnes, DeWitt, Wilson, Gonzales Counties in 2012

GOR
scf/bbl

Composition

Vapor
Liquid

Viscosity Effect

IP30   BOPD
IP30 max Gas vs. GOR
Karnes, DeWitt, Gonzales, Wilson (about 1400 wells)
“Oil” Wells with > 1000 BOPD IP30

Area where 1000 – 3000 GOR occurs at highest pressure
Eagle Ford liquids sweet spot

How to predict composition and pressure?

Reservoir Pressure  psi

Liquid

Vapor

3200 GOR

SWEET SPOT

10,000
Instantaneous vs. Cumulative

GOR increases during generation

120 °C

150 °C

180 °C

Trap

Cumulative

Instantaneous
Instantaneous vs. Cumulative GOR

“Western” Eagle Ford organofacies

Instantaneous

Cumulative

GOR

scf/bbl

Temperature (°C)

100
120
140
160
180
200
220

1000000
100000
10000
1000
100
10

vapor

liquid
Previous kinetic model

Reach “sorption” threshold of kerogen and then “expulsion”

Problem
Source rocks retain more petroleum than previously thought
Expel less than previously thought
Updated BP Kinetic Model

- Storage in *organic* and *inorganic* porosity
- Calculate volume of retained petroleum in source rock
- "Instantaneous" composition (GOR) is a "source rock" calculation

Source interval
Model the petroleum generation, plus…

Changes in inorganic and organic porosity

8% TOC
Carbonate-rich
Over-pressured

Porosity (fraction)

Inorganic porosity
High Sw

Organic porosity
0% Sw

Depth (m)
GOR predicted from Thermal Stress
GOR is close to an Instantaneous Composition
PVT GOR vs. Predicted GOR

Actual: 14,680
Model: 13,200

Actual: 6,509
Model: 4,500

Actual: 1,916
Model: 2,800

PVT data courtesy of Corelab
Eagle Ford Viscosity (modeled)

High pressure helps **mobility** of more viscous liquid phase fluids
What about Pressure?

\[ Q = \frac{k \times H \times DP}{m} \]
Over-pressure in source rocks

- Due to Petroleum generation?

- Due to Rapid burial?
  - Compaction disequilibrium

- How is over-pressure preserved?
Petroleum generation & over-pressure

Momper, 1979
- Volumetric expansion

Lewan, 1985
- Hydrocarbon generation
- Bitumen network
- Microfractures
- Expulsion

Lewan: Pyrolysis of Woodford Shale

Immature – dispersed organic matter

Mature – bitumen network develops
Eagle Ford Structure (m)

Eagle Ford

3000 – 7000 feet of exhumation in west; Less in east part of fairway
NW-SE Dip section

Maverick  Dimmit  Webb

Eagle Ford

Midway Shale

Escondido

Olmos

Lithology
- 90sa_10sh
- shale
- Midway Shale
- chalk
- marl
- limestone (early silt)
Eagle Ford Petroleum Charge

Vertical Migration from Eagle Ford
Eagle Ford charges overlying units
Eagle Ford also expels downward into Buda
Phase
Liquid updip & above vapor

Note vertical maturity trend in overlying Upper Cretaceous strata
Basin overpressure during Eocene

With petroleum generation & expulsion

Eagle Ford expulsion

Without petroleum generation & expulsion

...Still have overpressure
Difference in over-pressure
With and without petroleum generation & expulsion

With petroleum generation & expulsion

Without petroleum generation & expulsion

Real well data

Model

Eagle Ford

0.74 psi/ft

0.66 psi/ft

Mud Weight

10  12  14

10  12  14
Permeability is not just a function of facies or the rock
Permeability is also a function of pore pressure
Gas window and Over-pressure
Not completely linked… Why not?

Over-pressure in the Eagle Ford
psi above hydrostatic

Post-Laramide exhumation in west causes
loss of over-pressure and decoupling of
GOR and pressure contours

85 Ma
Exhumation: loss of pressure

Anadarko
Minor exhumation
Over-pressure preserved

Arkoma
High exhumation
Over-pressure lost

Isopach of eroded section
<table>
<thead>
<tr>
<th>Fairway</th>
<th>Exhumation</th>
<th>Over-pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arkoma Woodford</td>
<td>&gt; 10,000 ft</td>
<td>Mild to none</td>
</tr>
<tr>
<td>Fayetteville</td>
<td>&gt; 10,000 ft</td>
<td>Mild to none</td>
</tr>
<tr>
<td>Anadarko Woodford</td>
<td>&lt; 6,000 ft</td>
<td>High</td>
</tr>
<tr>
<td>Haynesville</td>
<td>&lt; 6,000 ft</td>
<td>High</td>
</tr>
<tr>
<td>Eagle Ford Central</td>
<td>&lt; 5,000 ft</td>
<td>High</td>
</tr>
<tr>
<td>Eagle Ford West</td>
<td>&gt; 6,000 ft</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
Exhumation can move fluid near two-phase point (bubble or dew point)

- **GOR** reflects burial
- **Same maturity**
- **Different phase**
- **Different mobility**

**Loss of Pressure**

**Two-phase**

**Single phase**

- **100's Ma**
- **0 Ma**

**Time**

**Depth**

**Exhumation**

**Burial & Maturation Over-pressure**
When might GOR prediction fail?

- **Substantial uplift**
  - Fluid goes two-phase during uplift
  - Produced GOR is higher than predicted
- **Wrong kinetic model**
  - Kinetics change as Organofacies change
- **Frack into depleted area**
- **Frack into underlying reservoir**
  - Petroleum migrated into underlying reservoir
  - Cumulative composition
Summary: Sweet Spots

- Fluid viscosity and reservoir pressure
  - First order controls on sweet spots in shale

- Retained petroleum predicted by right kinetic model
  - Viscosity and GOR are directly linked to maturity
  - Caution: Prediction can fail

- Over-pressure
  - Petroleum generation and compaction disequilibrium
  - Lost by substantial exhumation

- GOR and Pressure prediction require understanding of burial and uplift history!

\[ Q = \frac{k \times H \times DP}{m} \]
Thanks!

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Slides available at AAPG Search & Discovery
Cander, H., 2012