The advent of commercial hydrocarbon production from shale reservoirs is a relatively new phenomenon as it relates to petroleum geology. This presentation will look at all phases of the life cycle of an upstream project and will address the aspects that are generally unique to shale reservoirs. Unconventional exploration involves a different way of thinking:

Conventional

- Project identification focuses “outside in”
- Seismic control works “outside in”
- Stratigraphic support eventually focuses on the facies analysis local to the prospect
- Reservoir quality issues are relegated to the area of the prospect

Unconventional

- Project identification focuses “inside out”
- Seismic control works “inside out”
- Stratigraphic support focuses on analysis of the entire basin
- Reservoir quality analysis is required over a very broad area of the basin

Prospect Identification: Conventional Analogy

- Eagle Ford Shale Prospect
Known regional source rock across large petroliferous basin
- Reservoir quality and geochemical attributes poorly understood
- The area was >10MM acres with high side resource potential of >10 BBOE

Case Study for Unconventional Exploration involved the Hawkville Field. We targeted the Eagle Ford Shale based on its significance as a regional source rock. We mapped the Eagle Ford across the entire Gulf Coast Basin and identified an anomalously thick, porous and highly resistive Eagle Ford section in La Salle and McMullen counties. We acquired Eagle Ford cuttings on a key well and had them analyzed for TOC, VRO and other key parameters. In addition, we acquired ~160,000 acres and spud the initial test well. Completion occurred in October 2008 for 7.6 Mmcf/d and 251 Bc/d.

The Eagle Ford has proven to have all of the right ingredients for a world-class shale reservoir with petrophysical parameters that are among the best, if not the best, of any known shale reservoir. There is a wide range in depth (approx. 5,000'-13,000'/1,500m-4,000m) results in complete spectrum of hydrocarbon products. A majority of the trend is in moderate geopressure providing for significant hydrocarbon volumes in place. There is a favorable regulatory and mineral owner environment and these factors have lead to growth in the Eagle Ford that is truly unprecedented.
“The Discovery, Reservoir Attributes and Significance of the Hawkville Field and Eagle Ford Shale Trend: Implications for Future Development”

AAPG Eagle Ford GTW
February 24th, 2014
Richard K. Stoneburner

Formerly: President and COO Petrohawk Energy and President NA Shale Production Division BHP Billiton Petroleum

Currently: Advisor to Pine Brook Partners; Director for Newfield Exploration, Yuma Exploration and Cub Energy
Exploration Process
## Unconventional Exploration: A Different Way of Thinking

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Deep Water Gulf of Mexico Prospect
- Structurally controlled and supported by local analogs
- At time of Prospect Identification, three significant analogs in the area of the prospect
- The area of the prospect was on the order of 10K acres with resource potential of 10-200 MMBOE
Prospect Identification: Unconventional Analogy

- Eagle Ford Shale Prospect

- Known regional source rock across large petroliferous basin

- Reservoir quality and geochemical attributes poorly understood

- The area was >10MM acres with high side resource potential of >10 BBOE
Case Study for Unconventional Exploration: Hawkville Field

In early 2008 the CEO of Petrohawk charged the Exploration team to find another “Haynesville-like” play

- Our Fayetteville and Haynesville experience provided a level of experience in evaluating shale reservoirs that potentially allowed for a quick evaluation

We targeted the Eagle Ford Shale based on its significance as a regional source rock

- Q1: Mapped the Eagle Ford across the entire Gulf Coast Basin and identified an anomalously thick, porous and highly resistive Eagle Ford section in La Salle and McMullen counties.
- Q2: Acquired Eagle Ford cuttings on a key well and had them analyzed for TOC, VRO and other key parameters
- Q3: Acquired ~160,000 acres and spud the initial test well
- Q4: Completed it in October 2008 for 7.6 Mmcf/d and 251 Bc/d
Hawkville Field in Early 2008

- Very limited well control in prospective area

- Prospect was located in a regional setting between two divergent shelf margins which suggested the presence of a “mini-basin”

- While the geochemical properties were unknown, the depth range (10,000-11,500’/3050,-3500m) suggested a relatively mature source rock
Key Finding #1: World Class Petrophysical Properties

- Well was drilled in the early ‘90’s, probably targeting the Cretaceous Olmos Sands.

- Eagle Ford tested small amount of gas after light acid treatment.

- Over 250’ (75m) of Eagle Ford greater than 9% density, with majority greater than 15% (~100% Net/Gross).

- Excellent resistivity.

- Gamma Ray character indicative of “coarse” grained mudstone.
Key Finding #2:
Positive Geochemical Analysis

Phillips LaSalle #1
D&A in 1952

Eagle Ford Shale Gas Risk Assessment Diagram

- TOC (0-5)
- Ro (0.2 – 2.2)
- Tr (50 – 100)
- Tmax (435 – 470)
- Dryness (0 – 100)

Minimum Threshold
Phillips LaSalle #1
Key Finding #3:
Seismic Defines the Optimum Reservoir Thickness

- The anomalously thick Eagle Ford at Hawkville could be identified with 2D seismic data.

- A grid of existing 2D data was acquired that allowed the mapping of the Eagle Ford >150’ (45m).

Data courtesy of Seitel, Inc.
Hawkville Field in Late 2008

- Petrohawk Energy
  - Dora Martin #1H Spud
  - Date: 09/2008
  - 1st Prod: 01/2009

- Petrohawk Energy
  - STS #1H Spud
  - Date: 07/2008
  - 1st Prod: 10/2008

Fall 2008
Petrohawk Acreage Position
~160,000 net acres
The Eagle Ford Shale in 2013

Eagle Ford Shale Competitor Map
A New Set of Lights Visible From Space
Appraisal Process
The Appraisal Process:
Core Data and “Core to Log” Data is Critical

There is nothing more critical to the evaluation of a shale resource than
the extensive data gathered from whole core analysis:

- Measurement of “conventional” reservoir attributes such as Porosity, Sw,
  Permeability, etc.

- Identify and measure the mineralogy, specifically clay minerals versus “coarse
  grained” constituents

- Measurement of key geochemical (TOC, Thermal Maturity, etc.) and
  geomechanical attributes (Young’s Modulus and Poisson’s Ratio)

- Most importantly, calibrate core measurements to conventional open hole log
  suites, therefore expanding knowledge regarding reservoir characterization,
  formation evaluation (OGIP, Recovery and EUR) and optimization of the
  hydraulic fracture stimulation
Basic Petrophysical Workflow

Core Data Xplots

Interpreted Log Curves

Cluster Analysis

Facies Classification

TOC
Porosity
Permeability
Saturation
Lithology
Geomechanics

ALGORITHMS
Core to Log Calibration: TOC-Porosity-Permeability

TOC/RHOB

Fair correlation coefficient
\( r^2 \approx 0.65 \)

Porosity

Highest correlation coefficient
\( r^2 \approx 0.93 \)

Total porosity → HC-filled porosity → Permeability

Least dependable of the algorithms (use qualitatively and in localized zones)

Sw based on default Rw \( \approx 0.025 \)

Triple Combo
Core to Log Process: Expanding the Data Set

<table>
<thead>
<tr>
<th>GR-TOC RES</th>
<th>PORO-PERM SATURATION</th>
<th>LITHOLOGY</th>
<th>FRACTURE PROPAGATION</th>
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</thead>
<tbody>
<tr>
<td>Correlation</td>
<td>Organic</td>
<td>Depth</td>
<td>Resistivity</td>
</tr>
<tr>
<td>Top Shale</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Base Shale</td>
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- TOC distribution
- Sweetspot screening
- Rock properties from ECS-type tool should dovetail with geomechanical descriptions
- Frac properties from DTC-DTS
An Example of Utilizing the Expanded Data Set

Cluster Analysis
Poisson’s Ratio vs. Young’s Modulus
Lambda*Rho vs. Mu*Rho (or any other attribute combination)

Facies extracted from Crossplot
A Key Aspect of Quality Shale Reservoirs: Vertical Heterogeneity

Courtesy of Core Laboratories
Micro-Textural Relationships: The Importance of Scale

Standard 30 micron thick slide:
No apparent grain support which would suggest poor reservoir quality

Ultra Thin (20 micron) slide:
Significant grain support which leads to better reservoir quality

Courtesy of Core Laboratories
The Importance of “Coarse” Grained Constituents: Eagle Ford Shale

<table>
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<tr>
<th>Depth, feet</th>
<th>Volume Percent</th>
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<tbody>
<tr>
<td>11334.0</td>
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<tr>
<td>11350.5</td>
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MINERALOGY by XRD (PC-Q #1H)

- Qtz
- Plg
- Cal
- Dol
- Pyr
- Mar
- I/S
- I/M
- Chl
- Kao
- Ker

Austin Chalk
Eagle Ford
Buda

Courtesy of Core Laboratories
Eagle Ford: Mineralogical Variation Across the Trend

- Clay content increases from west to east
- Kerogen content remains relatively constant
- Increase in clay resultant from clastic influence of the East Texas Basin

[Chart showing mineralogical variation across different areas, courtesy of Core Laboratories]
The Importance of Stress

Isotropic ‘Tempered’ Glass: *One extreme*  
Anisotropic ‘Natural’ Glass: *The other extreme*

Preferred: Something in between

*Courtesy of Core Laboratories*
Development Process
The cost of 3D seismic data is minimal in the total field development cost, but is not critical to the exploration process.

3D seismic data is critical in identifying faults and dip changes that could compromise the stratigraphic targeting of a horizontal wellbore.

Merged ~650 square miles (~1100 square kilometers) of acquired proprietary data and licensed data in Hawkville Field.
Geo-Steering:
An Important New Geoscience Skill Set

- Horizontal drilling creates significant *geological* challenges
  - Unforeseen dip changes and/or faults can cause a well to be out of zone for a large portion of a lateral

- The combination of 3D seismic data and MD to TVD Gamma Ray correlation allows the geologist to direct the *drilling* operation to allow the well to stay within the target window

- The post-drill geologic interpretation of the wellbore can cause the *completion* engineer to design the fracture geometry to conform to the geology of the wellbore

- The use of the geologic interpretation can be utilized with *production* logs to determine which portions of the wellbore are contributing and why
Stage by Stage Fracture Stimulation Montage: Geometric Completions vs Geologic Completions?
The Eagle Ford After Five Years

- Approximately 10,000 wells have been permitted to date with more than 200 rigs operating and approximately 290 wells being drilled each month

- Average EUR across the play is ~450 MBOE

- Risked remaining resource is estimated at 28 BBOE from over 70,000 undrilled locations
  - Current B/E prices are $62/BBL rising to $100 by 2019

- At B/E price below $90/BBL, EOG and BHP have remaining resource 2.2 BBOE and 1.7 BBOE, respectively, with B/E price of $62/BBL

- Spacing assumptions range from 110 acres in the dry gas areas to 40 acres in the oil window

Eagle Ford Natural Gas Production Growth 2008-2013

NATURAL GAS

Source: Texas Railroad Commission Production Data Query System

2013 thru Q1
Eagle Ford Oil and Condensate Production Growth 2008-2013

OIL AND CONDENSATE

Source: Texas Railroad Commission Production Data Query System

2013 thru Q1
Eagle Ford Oil Drilling Permits 2008-2013

Source: Texas Railroad Commission Production Data Query System

2013 thru Q1
Eagle Ford Oil Drilling Permits 2008-2013

DRILLING PERMITS

YEAR

TOTAL DRILLING PERMITS

Source: Texas Railroad Commission Production Data Query System

2013 Annualized from Q1
Conclusions

- The Eagle Ford has proven to have all of the right ingredients for a world-class shale reservoir

  - Petrophysical parameters that are among the best, if not the best, of any known shale reservoir

  - A wide range in depth (approx. 5000’-13,000’/1500m-4000m) results in complete spectrum of hydrocarbon products

  - A majority of the trend is in moderate geopressure providing for significant hydrocarbon volumes in place

  - Favorable regulatory and mineral owner environment

- These factors have lead to growth in the Eagle Ford that is truly unprecedented