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Optimized Shale Resource Development using proper placement of Wells and Hydraulic Fracture Stages

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Outline

• Illustration of the Prize
• Present trend in Unconventional Reservoir Modeling and it’s impact on production
• Challenges the industry face to enhance recovery factor while reducing cost per unit of hydrocarbon recovered
• Where should the future engineers focus?
  – What technologies are there and what are needed in the near future to **optimally place wells** for the enhanced recovery
  – What technologies are there and what the industry needs in the near future to decide the **optimum placement of the hydraulic fracture stages**
• Illustrative field examples and the recommended way forward
Unconventional Gas Resource: A Global Phenomenon

Over 44,300 TCF
Gas in place resources

Source: Baker Hughes, EIA, SPE 68755, Kawata & Fujita from Rogner

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Unconventional Oil Resources 2-3 Trillion Barrels

- **Russia**
  - Bazhenov Shale WSB 1,600 BBO

- **Bakken** 24 BBO, Niobrara 3 BBO
- **Permian, Mississippian** 9 BBO
- **Utica, Eagle Ford, Barnett,** 15 BBO

- **Argentina Neuquén Basin** 23 BBO
- **Canada Cardium**
- **Europe** 100 BBO
- **MENA**
- **China**
- **Australia**
- **South Africa**

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Unconventional Oil Resources

- Oil Shales
- Extra-Heavy Oil and Bitumen
- Tight Oil/Gas Deposits

Sources: Oil Shales of the World: Their Origin, Occurrence and Exploitation by Paul L. Russel and UNITAR Heavy Oil and Oil Sands Database, 2010; Energy Information Administration, World Shale Gas Resources, 2011; and Hart Energy
Unconventional Development – Learning Curve
Barnett Shale Development

Maximum gas 6 mo. production (MCF)

- **Horizontal**
- **Vertical**
- **Directional**

- Small energized fracs
- Crosslinked massive hyd. fracs
- First horizontal well
- μ-seismic
- Slickwater
- Multistage Completions

Date:
Jan-81 Jan-83 Jan-85 Jan-87 Jan-89 Jan-91 Jan-93 Jan-95 Jan-97 Jan-99 Jan-01 Jan-03 Jan-05 Jan-07 Jan-09 Jan-11 Jan-13
A Closer Look at the “Shale Revolution”

70% of unconventional wells in the U.S. do not reach their production targets*

60% of all fracture stages are ineffective**

73% of operators say they do not know enough about the subsurface*

**Efficiency and Effectiveness are key for Proper Placement of Well and Frac Stage in Sweet Spots

**Source: Hart’s E&P, 2012
• Identify sweet spots
• Predict performance /EUR
• Where to place wells: Well placement, spacing, drainage area, lateral orientation, and length
• Which Method of completion: Open hole, cased hole,
• Optimal Stimulation design: Stage placement, number of stages, fluid, proppant, volume
• Production management: Flowback, managed rate of production
Unconventional Workflow: How is it Different?
Moving from Conventional To Shales

Conventional
- Porosity
- Saturations
- Permeability
- Resource Base
- Reservoir Pressure

Shales
- Reservoir Pressure
- TOC
- Ro (Vitrinite Reflectance)
- Thermal Maturity
- Brittleness

Black Shale
3.5\% TOC (avg)
0.83\% Ro (avg)
Technology Evolution and Production
Selected Unconventional Gas Basins, Onshore U.S.

Horizontal Gas Stages Per Well and Average Lateral Length.

- Average Per Well
- Stages Per Well
- Average Lateral length

Horizontal Gas Well Average

- 2006
- 2007
- 2008
- 2009
- 2010
- 2011

Source: BHI, HPDI, IHS, Company data
Source: HPDI
Three Key Elements To Avoid Sharp Production Decline

Hydraulic Fracture Model
- Single well treatment
- Fracture grid representation
- Geometries and properties

Reservoir Fracture Grids
- Multiple wells and stages
- Fracture refinement
- Various scenarios

Reservoir Flow Model
- Fit-for-purpose flow simulator
- Dec curves
- Drainage Scenarios

STIMULATION PERFORMANCE: REDUCE THE SHARP PRODUCTION DECLINE
Shale Reservoir Analysis

• Conventional reservoir modeling & analyses not effective for shale
• Shale reservoirs require new approaches to Analysis & Forecast
• An integrated “shale engineering” approach is required to plan wells, stimulate & forecast long-term production for economic evaluations

• SWEET SPOTS: Well and Frac Stage Locations

Black Shale
3.5% TOC (avg)
0.83% Ro (avg)
What is a “Sweet Spot”?

• The “Sweet Spot” is where the maximum power is generated with the least amount of effort and vibration.

• The Sweet Spot is important in these sports because we don’t all have perfect swings.

• What does this have to do with unconventional resources?
A “Sweet Spot” or “Core” represents the concurrence of several favorable parameters such as:

- TOC
- Kerogen Type
- Fluid
- Thermal Maturity
- Depositional Environment (Litho-facies)
- Depth
- Thickness
- Lithology/Mineralogy
- Porosity
- Pressure
- (Continued Productivity)

- Anisotropy
- Stress Regime
- Fractures
- Faulting
- Brittleness (Fracturability)

Sweet Spots are not Contiguous
Can we Identify Optimal Areas For Reservoir Stimulation Before Drilling and Frac’ing?

Zoback, Mark, 2012
Attribute Analysis + Lithofacies = Sweet Spot Identification

Location of LPLD events are correlative with amplitude anomalies.

Zoback, Mark, 2012
Multi-Attribute Prediction of TOC (WPCTOC)

Hampson & Russell
Haynesville Case Study

Courtesy of CGG and BHI Alliance
Locating Areas of High TOC in Seismic Volume

Volumetric View of TOC with well penetrations

Multiple uneconomic wells

Several TOC rich areas yet to be exploited

Courtesy of CGG and BHI Alliance
TOC (Total Organic Content) Vs. Acoustic Impedance

Lower Acoustic Impedance = Higher TOC and Natural Fractures

Pictured here (from top), near slack seismic section, Acoustic Impedance section and TOC section through the northern calibration well. The red arrows point at the top of the Spekk Formation and the black arrows point at the base. In the middle Acoustic Impedance section, the acoustic impedance is lower within the Spekk Formation than in adjacent strata, apart from in the shallowest part where the low impedances are due to the shallow depth and not due to organic content. A trend from very low acoustic impedances in the upper part (blue colors) to higher acoustic impedances further down (red and pink colors) is clearly seen within the Spekk Formation. TOC content greater than 6 percent TOC is highlighted in bright colors in the lower figure.

Graphics courtesy of Statoil Research Center

Source: AAPG Explorer. Dec 2009
Vertical Pilot Well: The start

TOC, Vitrinite Reflectance Ro, Thermal Maturity, Porosity, K, P, Natural fractures, faults, karsts, hazards
Moving from Pilot wells to development wells

Reservoir Navigation Services - RNS
(Azimuthal Resistivity & Gamma Images)
Armstrong Co., Pennsylvania – Marcellus Case History

Target for Lateral
High TOC = only 15ft Thick

Well Trajectory Planned
• Seismic
• Shale Analysis
• Offset Well Data

Monitored LWD GR
• Up and Down
• To determine if well approaching formation top or bottom / correct

Follow the high TOC, Ro, BI and Pp path
### Evaluating the Resource and Production Potential

#### Resistivity / Density / Neutron

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<th>Formation Lithology</th>
<th>Spectroscopy</th>
<th>Micro-seismic</th>
<th>Imaging</th>
<th>Large Diameter Coring</th>
<th>Deep Reading Shear Acoustic</th>
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<td>Fracture detection</td>
<td>Core analyses</td>
<td>Geomechanical properties from Wellbore and away from wellbore</td>
<td>Porosity Independent measure of total organic carbon</td>
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#### Logging and Core analyses can identify:
- Formation with producible source rock hydrocarbon
- Optimum formations to drill horizontal laterals
  - Optimall placement of frac stages
  - Potential barriers for frac containment
- Mineralogy key component integrated with Geomechanics
Mineralogy Varies in Shale Reservoirs
Wellbore Imaging: Fractures, Faults & Geohazards

WBM Imager

Acquire high-resolution resistivity formation images in...
Avoiding fault zone: don’t frac into water below target horizon

Targeting natural fracture swarms maximizes impact of the frac energy

Avoiding fracture swarms from adjacent wells frac job

Targeting natural fracture swarms maximizes impact of the frac energy

Eliminate nonproductive stages

Case Histories Show Production Increases above 20% and above 10% in EUR
Deep Shear Wave Imaging (up to 70m away)

• Methodology
  – Filtering direct waves
  – Reflected wave stacking
  – Reflector strike inversion
  – Fullwave data migration

• Benefits
  – Illuminate natural fractures up to 70 m away.
  – Identify mechanical strata
  – Placing laterals
The Next 5-10 Years
~100,000 Wells, 1-2 Million Hydrofracs

How Do We Optimize Resource Development?
Outside North America?: The Next 5-10 Years?
Wells, ? Hydraulic fracs

How Do We Optimize Resource Development?

Eastern Hm
UK
Poland
Russia
Turkey
Saudi Arabia
Kuwait
India
China
Indonesia
Australia
Croatia

Western Hm
Argentina
Mexico, Colombia
Venezuela
Ecuador
Brazil
Production from Nano-Darcy Rocks?

- Shale Resource has typically permeability in the nano-Darcy range
- Gas / hydrocarbon may move in order of few feet in a year!!
- What mechanism is there then to produce hydrocarbon from such low permeability rocks?
- Creation of a stimulated reservoir volume that has both longitudinal and shear fractures

![Diagram showing longitudinal bi-wing fracture and shear fracture envelope](image-url)
From **Natural** Shale to the **Artificial** Reservoir

**Benefits**

- Enhancing reservoir understanding
- Exploiting modern technology
Shale Engineering Predictive Model
Matched production history and production logging

✔ Frac stage contribution match
✔ Proppant placement match
✔ Well History match

Pressure Drop, psi

Narrow Uncertainty
Ball Activated Sleeve Open / Close Completion System

Varying Ball Sizes

Frac Sleeve in Closed Position

Ball with Frac Sleeve Open

Lighter than AL / Stronger than Steel
Extend and orientation of fractures created

This type of information allows engineers to optimize the fracturing staging and to optimize the placement of additional wells.
Relating stage contributions to production:
Impact on Field Development Plan

Events

Natural fractures

B-values

Rates measured by PLT 5 months later
Fracture Mechanics Based Model

\[
\sigma_h = \sigma_H, \text{ NF } 100 \text{ EW (90°)}
\]

\[
\sigma_h = \sigma_H, \text{ NF } 100 \text{ NS (45°)}
\]

\[
\sigma_h = \sigma_H, \text{ NF } 100 \text{ NS (0°)}
\]
Integrated Display

- Well Logs
- Layers
- Fracture Model
- Events
- Real-Time “SRV”
Concluding Remarks

- Shale resource is not contiguous and no two Shale basins are the same
  - Sweet spot identification is going to be critical (seismic attribute + Lithofacies) for well placement
  - Different shales will require different set of attributes and the associated lithofacies

- Geometric placement of hydraulic fracture stages needs to be replaced by shale productivity based parameters
  - Capitalize on the presence of natural fractures at the well bore as well as away from the wellbore
  - Avoid faults and geohazards
Your Feedback is Important

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http://www.spe.org(dl)