Abstract

As the quest for shale oil and gas spreads to South America, Europe, Asia and Australia, inevitably the operating practices of North America tend to serve as the template for the new, frontier areas. With either a sparse evaluation from logs, cores and cuttings or none at all, the ubiquitous approach for selection of zones for hydraulic fracturing in the long laterals in North America is to place 20 to 30 frac stages, more or less evenly spaced along the lateral, often without regard to variations in the reservoir properties. In many cases, especially in early stage frontier regions, a more comprehensive alternative approach that includes geological data integration to selectively optimize completion and stimulation intervals could be advantageous.

Specific field examples presented here show how each of the following can serve, in varying degrees, to delineate zones with better reservoir properties from those with poor reservoir characteristics: (i) Near real time measurements of XRF, XRD and pyrolysis on cuttings at the well site, (ii) a superior approach to monitoring the real-time hydrocarbon (C1-C8, benzene, toluene) and non-hydrocarbon gases (CO2, N2) dissolved in the drilling fluid in the mud stream, (iii) LWD spectral gamma ray and density measurements, (iv) LWD Shock wave acoustics, and (v) suites of openhole well logs obtained in horizontal shale gas wells. This enables the operator to concentrate frac dollars in zones that are more productive and at the same time avoid intervals that are not likely to be good producers. A relatively small investment in such surveys to delineate sweet spots could yield major dividends in enhanced productivity and improved utilization of frac dollars.

References


Focusing Stimulation Efforts on Sweet Spots in Shale Reservoirs for Enhanced Productivity

David Tonner, Weatherford Surface Logging Systems
Khaled H. Hashmy, Weatherford Geoscience
Samir Abueita, Anadarko Petroleum *
Jos Jonkers, Weatherford Reservoir Technologies

* Since Retired
Thank You

- Khaled Hashmy
- Jos Jonkers
- Samir Abueita
- Stephanie Heard
- Douglas Law
- Gbenga Yemidale
- Alan Morrison
- Frank Walles *
- Don Hall**

- Simon Hughes
- Mike Dix
- Nicolo Casarta
- Ryan King
- Tim Ruble
- Mark McCaffrey
- Rob Fulks
- Pat Jacobs
- Henderson Watkins

* Talisman Energy,  ** Pioneer Natural Resources
Definition - “The Sweet Spot”

- High TOC
- Rel. High Brittleness
- Rel. High $\Phi$, $K$, $S_H$
- Low Clay Content
- Mineral Filled Natural Fractures
- Optimal Stress Regime
Primary Core Evaluation Goals – Empirically Determine Key Shale Reservoir Properties

- Bulk Rock Properties
- Gas-in-Place Volume
- Oil-in-Place Volume
- Permeability to Gas and Oil
- Rock Mechanical Properties – “Fracability”
- Core-to-log Calibration
- Accurate Variable Input for Reservoir Modeling
Sweet Spot: Identification Methods

- In Verticals and Laterals Mud gas and Cuttings are a by-product of the drilling operation.
- Advanced Mud Gas Extraction/Detection
- Cuttings analysis
  - XRF, XRD, & Pyrolysis on Cuttings
    1. In Pilot Holes
    2. In Laterals
- Logging While Drilling
- Wireline Logging
Wellsite Geoscience – Cuttings Analysis

Sample Prep & Fume Hood

SRA & XRD

XRF

Data Analysis Center

Focusing Stimulation Efforts on Sweet Spots in Shale Reservoirs for Enhanced Productivity
Programmed Pyrolysis

**SRA Portable Pyrolysis Instrument provides:**
- Free Hydrocarbon (Gas/Oil) Content – $S_1$
- Remaining Hydrocarbon Generation Potential – $S_2$
- Organic richness – TOC
- Thermal Maturity – $T_{\text{max}}$
Direct Measurement of All Major Minerals

- Quartz
- K-Feldspar
- Plagioclase
- Total Clay
- Calcite
- Dolomite
- Siderite
- Pyrite
- Anhydrite

Procedures developed from laboratory bulk XRD analysis
Focusing Stimulation Efforts on Sweet Spots in Shale Reservoirs for Enhanced Productivity

XRD/PYROLYSIS DATA DEFINE TARGET ZONE

150 Foot Refined Target Interval

AAPG ICE, Singapore, September 15th to 19th 2012

Focusing Stimulation Efforts on Sweet Spots in Shale Reservoirs for Enhanced Productivity
Benchtop when compared to hand held device provided greater range of elements and superior accuracy and precision

• XRF measures 10-12 Major Elements (oxide wt%)
  SiO$_2$  TiO$_2$  Al$_2$O$_3$  Fe$_2$O$_3$  MnO  MgO  CaO  Na$_2$O  
  K$_2$O  P$_2$O$_5$  (plus S and Cl for most lithologies)

• XRF measures 18 Trace Elements (ppm)
  V  Cr  Co  Ni  Zn  Ga  As  Br  Rb  Sr  Y  Zr  Nb  
  Mo  Ba  Hf  Th  U

• Many minerals show considerable variability in their elemental composition, particularly with regard to trace elements.
Wellsite Cutting Analysis Work Flow

1. Commence with XRD/XRF and Pyrolysis on Pilot vertical holes and laterals.
2. Establish proxies for TOC with Trace Elements.
3. Resolve Mineralogy from the elemental data set.
4. As uncertainty is reduced move to XRF only.
Correlation of Pyrolysis TOC with Trace Metals

<table>
<thead>
<tr>
<th>Depth</th>
<th>Stacked Curves</th>
<th>Relative Brittleness</th>
<th>TOC V</th>
<th>TOC Ni</th>
<th>TOC SO3</th>
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<tbody>
<tr>
<td>3200</td>
<td></td>
<td></td>
<td>0</td>
<td>3.5</td>
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<td>3350</td>
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</table>

Permian Basin, W Texas

Scale: 1:1000

Focusing Stimulation Efforts on Sweet Spots in Shale Reservoirs for Enhanced Productivity
Haynesville Formation (Late Jurassic)
Texas - Louisiana

From Dix et al. (2010)
Chemosedimentology for Gas Shales

Redox-sensitive metals are excellent proxy for organic richness
From Dix et al. (2010)

Increasing organic richness
Focusing Stimulation Efforts on Sweet Spots in Shale Reservoirs for Enhanced Productivity

XRF On Cuttings Compared To Elemental Capture Tool on Wireline

<table>
<thead>
<tr>
<th>Elemental Units</th>
<th>ElementalGR</th>
<th>Fe2O3</th>
<th>Al2O3</th>
<th>K2O</th>
<th>MgO</th>
<th>Na2O</th>
<th>P2O5</th>
<th>MnO</th>
<th>SiO2</th>
<th>CaO</th>
<th>TiO2</th>
<th>SO3</th>
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<td>Unit 6-1</td>
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</tbody>
</table>
• **Calculated for Barnett Shale – good first approximation**

• **In reality, formula must be customized to each shale formation**
Brittleness Calculation Requires Local Geologic Input

Brittleness calculation requires Local geologic Input

Combine with CMI and X-Dipole Sonic

Trace Metals indicate areas of high TOC
Eagle Ford Shale is Calcite-Dominated

42% Calcite by XRD

60% Calcite by XRD
Mud Gas Extraction

Traditional agitator-based methods of extraction are inefficient and preferentially extract light-end alkanes.

Elder, S.S, Delaune,P, Williams, Hawker, Brumboi, Law

**Traditional Gas Traps Not Efficient**

After 1 minute of agitation only 25% of methane is extracted from the mud. After 7 minutes there is still 25% of methane kept in the mud. It takes 15 minutes of agitation to remove 90% of methane from the mud.

![Diagram](image-url)
Advanced Mud Gas Measurement

- C1-C8
- Benzene
- Toluene
- Ethene
- N₂
- CO₂
- 55 Sec.
- Gas In/Out

- Critical fluid properties can be predicted directly from mud gas sample
- Need good calibration data set and good mathematical models

Delineates top and bottom of the reservoir
Identifies changes in fluid type
Can optimize downhole fluid sampling
Reducing uncertainty of recycled gas effects

### Delta Gas Measurement System

<table>
<thead>
<tr>
<th>Active Mud Pit (in)</th>
<th>Flow Line/Possum Belly (out)</th>
<th>Using a delta system allows us to remove the effects of recycled gas, giving a more representative data set</th>
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</thead>
<tbody>
<tr>
<td>MD ft</td>
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<td>Increasing gas levels due to recycled gas in the system suggest false sweet spots</td>
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<table>
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<tr>
<th>MD ft</th>
<th>10000</th>
<th>11000</th>
<th>12000</th>
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<td>10000</td>
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<td>EMA %</td>
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<td>1.0%</td>
<td>0.1%</td>
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</table>

**Graphical Representation:**

- **Wellpath Mudlogging THD GC-TRACER THD**
- Using a delta system allows us to remove the effects of recycled gas, giving a more representative data set.
- Increasing gas levels due to recycled gas in the system suggest false sweet spots.

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AAPG ICE, Singapore, September 15th to 19th 2012
Identify Hydrocarbon Zones with Advanced Gas Detection

Increase in THC above background.

Green shading represents oil.

Upper Eagle Ford

Lower Eagle Ford

Crossover indicates the presence of hydrocarbons. As the area increases, the fluid density decreases.
Mudgas Data in Lateral Indicates Productive Zone

Eagle Ford Reservoir Characterization from Multisource Data Integration
*N. Basu1, G. Barzola1, H. Bello1, P. Clarke1 and O. Viloria1

Search and Discovery Article #80234 (2012)
Mudgas and Oil Production

Max Tgas from mudlogs and initial oil production is related mainly to presence of faults and associated fractures (high-order geometries); high-resolution coherency is detecting mainly high-angle faults.

Eagle Ford Reservoir Characterization from Multisource Data Integration* N. Basu1, G. Barzola1, H. Bello1, P. Clarke1 and O. Viloria1 Search and Discovery Article #80234 (2012)
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CUSTOMIZED FRAC TREATMENTS FOR SPECIFIC ROCK TYPES

- WHTP
- Type of Proppants
- Amount Of Proppants

Fluid Selection
- Oil/Condensate
  - Gels
  - Cross Linked Gels
- Gas Window Slick
  - Water or Linear Gel for entire job
  - Fluid Determines Proppant Size

Cocktail A
- 600’ of Lateral
- 17% of The Lateral

Cocktail B
- 2000’ of Lateral
- 57% of The Lateral

Cocktail C
- 900’ of Lateral
- 26% of The Lateral

Conductivity requirements in liquids rich area Larger proppant Mesh sizes (30/50 and 20/40)
Effect of Proppant on Productivity

Eagle Ford Average Cumulative Production per well

- Tier 1 Lightweight Ceramic - 6 mos
- Tier 1 Lightweight Ceramic - 12 mos
- Other Proppant - 6 mos
- Other Proppant - 12 mos

35% increase
$1.5 million value*

65% increase
$1.7 million value*

399 wells with 6 months production
254 wells with 12 months production

SPE Eagleford Workshop, 21-23 August 2012, San Antonio, Texas, Charles Pope, Complete Shale
• Good agreement between element-derived TOC and gas-derived total hydrocarbons
Wellbore Containment

- Wellbore maintained within +/- 10 feet of key brittle bed
EagleFord Completions Production Oil Tracers (Pseudo Production Log)

Eagle Ford Shale Workshop  San Antonio, Texas , Rick Tompkins,  EF Energy
Focusing Stimulation Efforts on Sweet Spots in Shale Reservoirs for Enhanced Productivity

Characterization of Lateral With LWD

Shear Velocity Image

Compressional Velocity Image

Horizontal Acoustic Semblance

Vertical Acoustic Semblance

Shear Anisotropy Ratio

Compressional and Shear Velocities

Formation Dip

Gamma Ray Image

Spectral Gamma Ray K, U, Th

GR, Borehole Survey & TVD
Wireline Identifies Sweet Spot
Case Study

Technology Toolbox - 2008
Seismic - Missing the Target

Well Out of Target

1) Lateral planned entirely from pilot logs
2) No 3D seismic used for well planning
3) No LWD data or Geo-steering (logs run thru-casing @ TD)
4) Cuttings/gas indicated mostly in Middle EGFD

= well 85% out of TARGET
Could not place proppant (note high Frac Gradient)

Circles scaled to relative amount of proppant placed per stage (ranging from 70M# to 143M#)

Reproduced with permission from J. D. Hall, Pioneer Natural Resources
Optimal Well Placement and Completion

Technology Toolbox
Seismic - Hitting the Target

Well In Target

Lessons Learned
1) Geo-steer all wells in-house (LWD GR)
2) Integrate seismic for planning and steering
   = well in target zone for efficient stimulation

Pilot GR log

Upper EGFD

Middle EGFD

Target

100 % In target

Circles scaled to relative amount of proppant placed per stage (ranging from 208M# to 324M#)

RA Tracer Log

RAtracer

stages
- Antimony
- Scandium
- Iridium
- No RA trace
- Frac-Gradient

Total Gas

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Focusing Stimulation Efforts on Sweet Spots in Shale Reservoirs for Enhanced Productivity
CONCLUSIONS

• XRF/XRD/Pyrolysis on cuttings offer a rapid, near real time approach to quantify mineralogy, elements and TOC in both vertical and lateral holes.

• Advanced Mud Gas extraction/detection provide real time, high resolution data for fluid typing and fracture identification in both vertical and lateral holes.

• LWD Spectral GR provides real time data on Kerogen content.

• LWD/Wireline Logs provide detailed petrophysical characterization of the lateral.
CONCLUSIONS

• These data sets can be used to;
  - Improve wellbore placement and containment
  - Reduce fracing in poor reservoir intervals
  - Focus completions in quality reservoir intervals
  - Assist with design of appropriate frac parameters
  - Assist with design of optimal frac placement

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