Drilling Challenges in Extreme Step-Outs with Emphasis on Shales

Hernando Jerez - Halliburton
Drilling Optimization Champion
# Drilling Challenges in Extreme Step-Outs with Emphasis on Shales

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</tbody>
</table>
North American Shale Plays

History of Shale Developments

1980 → 1990 → 2000 → 2010

Barnett
- Discover
- Develop
- Mature

30 years

North American Shales
- Discover
- Develop

Woodford
- Discover
- Develop

Haynesville
- Discover/Develop

Eagleford

Quantify Construct Complete Analyze

Gas Rate (Mscf/D) Oil Rate (bbl/D)

Time (Days)
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Typical WELL ARCHITECTURE in Haynesville Field.

Build the curve in 6 ¾” hole with a build radius of 10 degrees per 100 feet to land out at the desired target depth and hole angle. Continue drilling the 6 ¾” hole size thru the entire Horizontal section.
<table>
<thead>
<tr>
<th></th>
<th>Eagle Ford</th>
<th>Woodford</th>
<th>Haynesville</th>
<th>Bakken</th>
<th>Marcellus</th>
<th>Barnett</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbon Type</td>
<td>Oil - Gas</td>
<td>Oil-Gas</td>
<td>Gas</td>
<td>Oil</td>
<td>Gas</td>
<td>Gas</td>
</tr>
<tr>
<td>TVDepth (ft)</td>
<td>4,000-13,000</td>
<td>6,000-9,000</td>
<td>10,000-13,500</td>
<td>9500-11000</td>
<td>6,000-8,000</td>
<td>6,000-9,000</td>
</tr>
<tr>
<td>Thickness (ft)</td>
<td>50-200</td>
<td>100-220</td>
<td>60-300</td>
<td>10-60</td>
<td>50 - 250</td>
<td>300 - 500</td>
</tr>
<tr>
<td>Horizontal section</td>
<td>5000-6000</td>
<td>1500-4000</td>
<td>4000-5000</td>
<td>4000 - 10000</td>
<td>2500-5000</td>
<td>2000-3000</td>
</tr>
<tr>
<td>Temp, F</td>
<td>300 - 320</td>
<td>175 - 180</td>
<td>320-350+</td>
<td>200-220</td>
<td>130-150</td>
<td>160-170</td>
</tr>
<tr>
<td>Wellbore Orientation</td>
<td>NW - SE</td>
<td>N - S</td>
<td>N - S</td>
<td>EEN-WWS</td>
<td>NW - SE</td>
<td>NW - SE</td>
</tr>
<tr>
<td>Well Trajectory</td>
<td>3D</td>
<td>3D</td>
<td>3D</td>
<td>3D</td>
<td>3D</td>
<td>3D</td>
</tr>
<tr>
<td>Production hole</td>
<td>8 3/4&quot;</td>
<td>8 3/4&quot;</td>
<td>6 1/2&quot; - 6 3/4&quot;</td>
<td>6&quot;</td>
<td>8 3/4&quot;</td>
<td>8 3/4&quot;</td>
</tr>
<tr>
<td>DLS deg/100ft</td>
<td>12 - 16</td>
<td>10 - 15</td>
<td>13-18</td>
<td>10 -15</td>
<td>8 - 12</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Mud Type /density</td>
<td>OBM / 14 - 14.6</td>
<td>OBM / 9 - 9.5</td>
<td>OBM / 14 - 16</td>
<td>OBM / 10 - 12</td>
<td>KCl / 10-13</td>
<td>Saltwater/9.5</td>
</tr>
</tbody>
</table>
Typical WELL PAD Design

- 3D Trajectories
- Production Hole along shale including vertical, building and lateral sections
- 3D in the curve (building section)
- Preferential wellbore Orientation – minimum horizontal stress
- Collision avoidance
Actual Experience

- Different players with relevant experience
- Important learning curves
- Different field development plans
- Fit for purpose drilling rigs
- Tailored drilling services
- The presence of natural fracture network is very important
- The stimulation technique needs to be tailored to the individual shale reservoir and shale type
- Until recently, all the successful shale projects have been in brittle shale
- Logs help to determine good wells from bad wells
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Drilling Challenges

1. Optimal Well Trajectory
   • Maximize shale borehole exposure via horizontal wells
   • Borehole stability and wellbore orientation
   • Geosteering and wellbore placement
   • Geological uncertainties and formation changes

2. Minimizing NPT
   • Fewer problems, ideal operating environment
   • Well control issues
   • Smooth Drilling Operation by preventing
     ✓ High T&D
     ✓ Poor hole cleaning
     ✓ Extra trips
     ✓ Limited ROP
Drilling Challenges

3. High Pressure / High Temperature
4. Enhancing Economics
   • Drilling Efficiency
   • Minimize drilling fluid formation damage
   • Drill to the Fracture
     ✓ Optimize borehole placement in the reservoir
     ✓ Deliver a hole suitable for hydraulic fracture
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Shale Development Strategy

**WELL PLANNING / WELL CONSTRUCTION**

- Increase efficiency of drilling designs and determine best well-bore placement.
- Field Development Path Planning
- Directional Planning
- Drilling Data Management
- Tubular Design
- Wellbore Design
- Total Drilling Performance

**FORMATION EVALUATION**

- Methodical approach to identify unconventional shale reservoirs
- Use available core analysis to refine the model
- Shale reservoir type identification
- Identification of frac barriers
- Estimated gas content and gas in place

**STIMULATION**

- Tailor stimulation treatment
- The stimulation technique needs to be tailored to the individual shale reservoir and shale type
- All shales are different, Utilize calibrated petrophysical models
- Identify “best” rock for perfs and horizontal targets
- Minimize fluid damage to the reservoir

**COMPLETION EVALUATION**

- Well completion criteria
- Shale Analysis Brittleness Index calculation, with effective porosity, highlights optimum completion zones
- Delta Stim sleeves w/Swellpackers is now preferred method
# Customer Challenges/Solutions

<table>
<thead>
<tr>
<th>Challenge Area</th>
<th>Solution</th>
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| Optimal Well Trajectory         | - Collaborative well planning  
|                                 | - The right technologies to stay and steer in the sweet spot             |
| Minimizing NPT                  | - Optimized Drilling Performance collaboration and integration of every aspect of drilling  
|                                 | - Managed Pressure Drilling (MPD) Service allows to drill along the shale faster and safely |
| High Pressure / High Temperature| - High Temperature DownHole tools ensures continue drilling              |
| Enhancing Economics             | - Drilling and evaluating a well to in order to optimize a stimulation completion to maximize ultimate recovery |
| Improve recovery from reservoir  | - Lateral branches can be used to access otherwise unrecoverable reserves |
Collaborative Well Planning

1. Topography
2. Identify Subsurface
3. Formation Grids – Tops and Bottoms
4. First Pass Laterals
5. Pad Placement
6. Slot Assignments
7. Well Nudging
8. Field Updates
9. Final Plan
Precise Wellbore Placement

- Reservoir information is critical, but it has to be cost effective
- Pilot holes must be logged
  - Get maximum reservoir info with minimum cost and exposure
- Geo Steering
  - keep the well on target and to get critical properties along the horizontal lateral
- Chemostratigraphy
  - critical reservoir information along the horizontal lateral
Drill a Horizontal Well

- Efficient wellbore construction: Directional Tools, LWD recommended GR – Sonic, Geosteering, Laserstrat, Real Time Reservoir Characterization
Fit-for-Purpose Downhole Motors

- One Trip System (Vertical, Curve and Lateral)

- Shorter bit to bend
  - Higher Build Rates with less bend angle
  - Reduced trips (not re-adjusting motors)
  - Motor is fully rotational in any section of the well
  - Better gauge hole due to bit drilling on center
  - Reduced hole spiraling due to bit drilling on center

- Reduce twist off risk using larger bearing mandrel and stronger connection
Keys to bit selection for horizontal shales

- Hole cleaning
- Bit cleaning
- Balance durability and speed
- Directional control
- Gauge protection
- Mineralogy dependent
Benefits of Rotary Steerables:

- Reduced NPT associated with:
  - orienting motor toolfaces
  - re-logging for LWD images
  - simplified operations (reduce wipers, backreaming)
- On bottom time improved = improved overall ROP
- Higher rotary speeds = improved hole cleaning
- Produce high quality borehole while improving directional control:
  - eliminate spiraling
  - centric (not eccentric) hole
  - minimize tortuosity
- Improves weight transfer, leads to:
  - smoother casing/liner running operations
  - longer, extended reach, wells possible
Challenges with RSS

- Higher build rates
- Hole enlargement
- Stick-slip vibration
- Is the bit matched to application?
- Pipe & casing wear considerations
- Higher tool & replacement cost

Is the benefit worth the additional risk?
Drilling Optimization Tools

- Reduce inefficiency and uncertainty
- Measure within a few feet of the bit
- Reaction time is greatly improved
  - corrections are quick and results are verified immediately
  - Less time is spent in the oriented (sliding) mode
- Higher average rate of penetration
- More precise wellbore placement in the reservoir

ABI™ (at-bit inclination) sensor

PWD measurements provide the knowledge to:

- Avoid lost circulation
- Detect flow/kicks before they happen.
- Reduce the risk of problems caused by unexpected fracture or collapse.
- Identify ineffective cuttings removal and poor hole cleaning
- Help to maintain wellbore pressures between safe operating limits and to monitor hole cleaning.
Drilling Optimization Tools

- Real-time measurements of weight, torque and bending moment to characterize the transfer of energy from surface to bit.
- These measurements help optimize drilling parameters to maximize performance and minimize wasted energy transfer and vibration.
How We Define HP/HT

- **Ultra HP/HT**: >20K psi (138 MPa)
- **Extreme HP/HT**: >15K psi (103 MPa)
- **HP/HT**: >10K psi (69 MPa)
- **Standard**

**Pressure**
- >20K psi (138 MPa)
- >15K psi (103 MPa)
- >10K psi (69 MPa)

**Temperature**
- >300°F (175°C)
- >350°F (175°C)
- >400°F (200°C)
## Temperature & Pressure Capability – 2011

<table>
<thead>
<tr>
<th>Tool</th>
<th>Maximum Operation Pressure (psi) &amp; Temperature (°C)</th>
<th>9½”</th>
<th>8”</th>
<th>6¾”</th>
<th>4¼”</th>
<th>3 3/8”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rotary Steerable</strong></td>
<td></td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
<td>175</td>
<td>20,000</td>
</tr>
<tr>
<td><strong>Directional</strong></td>
<td></td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>PWD</strong></td>
<td></td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Gamma</strong></td>
<td></td>
<td>25,000</td>
<td>175</td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Resistivity</strong></td>
<td></td>
<td>25,000</td>
<td>175</td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td></td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Neutron</strong></td>
<td></td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
<td>175</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Sonic</strong></td>
<td></td>
<td>25,000</td>
<td>150</td>
<td>25,000</td>
<td>150</td>
<td>25,000</td>
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<tr>
<td><strong>Formation Tester</strong></td>
<td></td>
<td>25,000</td>
<td>150</td>
<td>25,000</td>
<td>150</td>
<td>25,000</td>
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<tr>
<td><strong>TurboPower Turbines</strong></td>
<td></td>
<td>30,000</td>
<td>300</td>
<td>30,000</td>
<td>300</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>GeoForce Motors</strong></td>
<td></td>
<td>30,000</td>
<td>200</td>
<td>30,000</td>
<td>200</td>
<td>30,000</td>
</tr>
</tbody>
</table>
Managed Pressure Drilling (MPD)

- An adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore.

- The objectives are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly.

- It is the intention of MPD to avoid continuous influx of formation fluids to the surface.

- Any influx incidental to the operation will be safely contained using an appropriate process.
Optimized Drilling- Shale Solution

**Customer Challenge:**
- Reduce well construction cost
- Improve recovery in shale
- Increased production rates

Drilling technique developed to perform Optimized Pressure Drilling. It is used when the bottom-hole pressure needs to be controlled more tightly than traditional overbalanced drilling techniques.

Meets Shale drilling challenge by:

1. Taking the pumps “on / off “pressure cycle off the formation which will improve borehole stability by reducing the spurt loss of fluids into the shales.
2. The MW can be designed statically lower than the collapse pressure and allow ECD to be slightly above using surface pressure applied with the choke.
3. ECD deltas on connections can be compensated with the automated MPD system.
4. Additionally, drilling closer to the lower pressure limit in MPD mode will reduce the degree of overbalanced and be less damaging to the reservoir than conventional drilling.
Challenge: Wellbore Construction
Narrow Margin-Casing Design

Casing Program

<table>
<thead>
<tr>
<th>Bit Size</th>
<th>Length</th>
<th>Depth</th>
<th>Static Mud Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>298.5 mm</td>
<td>165 m</td>
<td>541 ft</td>
<td>69.94 kg/m 45.6 lb/ft</td>
</tr>
<tr>
<td>219.1 mm</td>
<td>852 m</td>
<td>2795 ft</td>
<td>41.67 kg/m 28.6 lb/ft</td>
</tr>
<tr>
<td>200.0 mm</td>
<td>1700 m</td>
<td>5577 ft</td>
<td></td>
</tr>
</tbody>
</table>

Open Hole

<table>
<thead>
<tr>
<th>Bit Size</th>
<th>Length</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>200.0 mm</td>
<td>1700 m</td>
<td>5577 ft</td>
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72 psi kick at 472m = 10.37 ppg EMW
Could pressure be communicated through fracture.

Fracture depth base on pressure = 515m
Well Planning: Drill-to-Frac

- Drill-to-Frac
- Single Fracture
  - Single
  - T-shaped
    - Multiple
    - Reorientation
- Multiple (at wellbore)
- Multiple Fracture (away from wellbore)

\[ \sigma_{\text{overburden}} \]
\[ \sigma_{\text{max}} \]
\[ \sigma_{\text{min}} \]
\[ \sigma_{\text{Hmax}} \]
\[ \sigma_{\text{Hmin}} \]
**Drill-to-Frac Process For Optimized Stimulation & Production**

- **Customer Challenge:**
  - Maximize IP & ultimate recovery through
    - Superior well bore placement
    - Optimized stimulation completion

Drilling and evaluating a well to in order to optimize a stimulation completion to maximize ultimate recovery

Drill-to-Frac meets the Shale play challenge by:

1. Bringing proven drilling technology to optimize drilling while maintaining the highest quality wellbore.

2. Precisely place the well bore in the best quality reservoir rock with the geonavigation and specific sensors like the Azimuthal Deep Resistivity tool and the Chemostratigraphy cuttings-based elemental analysis.

3. Accurately evaluate the well bore with the right formation evaluation tool sensors for input into the ShaleLOG stimulation answer product to predict reservoir rock properties for simulation design.
Efficient Solutions… Shale Plays

- **Customer Challenge:**
  - Maximize ultimate recovery through
    - Superior well bore placement
    - Optimized stimulation completion

A solution which involves multilateral wellbore placement across areas of fracture interest with a means to optimally deploying a pressure isolated stimulation completion to deliver immediate and long term recovery.

Meeting the Shale play challenge by:

1. Bringing proven Multilateral Technology to optimize junction placement and provide defined and precise junction exit geometry.

2. MLT sealed and supported junction to accommodate stimulation, completion and intervention tools.

3. Ability to isolate the junction from fracture pressures allowing high pressure and high volume fracturing/stimulation.
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</table>
- Optimal BHA is one that can drill both the Curve and Lateral section all in one run.

- The challenge is a Motor/Bit match design that will get the needed build rates with good steerability in the Curve.

- Bit-Balanced, good steerability, aggressive enough to drill lateral section.

- High Speed / High Torque Motor with 2 degree fixed housing with 5 7/8” bearing Stabilizer.

- MWD- 4 3/4” Standard Directional & Gamma.
HDBS DRILL BIT
1 BHA to Drill The Curve & Lateral

Recent Success
Major Operator
Red River Parish

Run length (ft) 5931
Interval drilled (ft) 10540 - 16471
ROP (ft/hr) 42.2
WOB (klb) 4 - 12
RPM 240 - 300
Motor 5/6 lobe 8.3 stg.
PP (psi) 4100
Flow rate (gpm) 240
Dull grade 1-1-BT-C-X-I-CT-TD

Inc In - 0 Inc Out - 85.5

---

6-1/2” (165mm) FX55

**PRODUCT SPECIFICATIONS**
- **Choke Type**: 3X - Conventional Drilling
- **HDC Code**: M402
- **Body Type**: MATRIX
- **Total Cutter Count**: 32
- **Cutter Distribution**
  - Face: 0
  - Groove: 5
  - Up Drill: 0
- **Number of Standard Nozzles**: 0
- **Number of Small Nozzles**: 5
- **Number of Ports**: 0
- **Joint Slot Area (sq in)**: 12.5
- **Normalized Face Volume**: 46.02
- **API Connection**: 3-1/2 REG. PIN
- **Recommended Make-Up Torque***: 5,700 - 7,905 ft-lb
- **Nominal Dimensions**
  - **Makeup Face to Nose**: 8.1 in - 215 mm
  - **Groove Length**: 1.5 in - 38 mm
  - **Sleeve Length**: 0 in - 0 mm
  - **Shank Diameter**: 4.5 in - 114 mm
- **Break-Out Force (Max. Legacy)**
  - **Approx. Shipping Weight**: 1035 lb - 460 kg

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**SPECIAL FEATURES**
- Managed TSP Groove, Up-Drill Cutters on Gauge Pass

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*The recommended make-up torque is a function of the drill pipe and usual bit size. Use with caution in applications in any holes greater than 6-1/2".

**Design dimensions are nominal and may vary slightly on manufactured product. Halliburton Drill Bits and Services models are continuously reviewed and refined. Product specifications may change without notice.

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www.halliburton.com
Drill to Frac

BP George A9H – 9 of 10 Water Fracs Placed – PL rate 8.2 MMCF/D

BP CGU 13-17H – 6 of 10 Fracs Placed > 50% – PL rate 4.5 MMCF/D
MPD operation

- MPD Original Objective: ROP improvement
- There has been a 3 to 4 fold increase in the ROP
- Additionally NPT has been minimal due to hole issues
- We were able to drill the 8 3/4” hole section to TD and keep the unstable shale.
- The open hole was >4000 ft drilled MPD system

- Based on our MPD engineers recommendation the mud weights used were several ppg lighter than those originally planned and was very close to balance statically. The bottom hole ECD was adjusted to the target using the auto choke system.
Thank You

- Questions?