Horizontal Well Planning Within the Woodford and Other Gas Shales Within the Mid-Continent, USA

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Hz Well Planning within Gas Shales – Key Topics

- Lateral placement, based on mineralogy
- Drilling direction, based on local stresses
- Staying in the zone, based on LWD/MWD
- Completion plan, based on borehole images or sonics
- Stimulation
- Production Log – did it work?
This is what we’re seeing on production logs….

Flow Scanner* observations:
- contribution to gas production varies between perforation clusters
- 75% of water production is from 4 toe perforations (stage one)
- 20% of gas productions is from 4 toe perforations (stage one)

Solution:
- operator plugged the four toe perforations and eliminated 80-85% of water production (1000 bwpd) with a minimal drop in gas production

Wouldn’t it be nice to have geologic information to explain these results?
Intro to Horizontal Well Planning in Gas Shales

The key to success in horizontal well projects within gas shales is to set up, plan and execute an effective completion design.

Step 1: Lateral placement – pilot hole evaluation
- Geochemical log (ECS) to quantify mineralogy and play potential
- Borehole images for structural dip, fracture, fault and stress analysis

Step 2: Drilling direction depends on local stress regime
- Borehole images or advanced sonic tools for stress orientations
  - Drilling fractures form parallel to present day maximum horizontal stress direction
  - Fast shear azimuth is parallel to present day maximum horizontal stress direction

Step 3: Completion planning – Hz well evaluation
- Borehole images or advanced sonic tools for rock stiffness
  - Resistive vs. conductive mineralogy on borehole images
  - Rock mechanical properties for fracture closure stress
- Borehole images for structural dip, fracture, fault and stress analysis
  - Dip changes may indicate folding or faulting (higher stresses)
  - Natural fractures enhanced system perm, may be related to faulting, can be good or bad
  - Drilling fractures help us predict hydraulic fracture initiation and geometry
Shale Minerals

Gas Shales
- Quartz Rich
- Frequent Carbonates
- Illite Dominant Clay
- Chlorite Common
- Periodic Swelling Clays
- Pyrite Common
- Variable Kerogen

Typical

Thirteen Fingers

Woodford

Barnett

Caney

Kerogen

Gas-filled porosity
Reservoir Evaluation for Lateral Placement

**TARGET**

- Geochemically (ECS)-enhanced formation evaluation
  - Quantitative mineralogy
    - High silica, low clay = better reservoirs and higher modulus
    - Swelling clays = big problems

- Borehole images → FMI/OBMI/UBI
  - Natural fractures
  - Drilling-induced fractures
  - Faults
  - Bed orientation
Mineralogy: Variable Characteristics = Variable Treatments

Resistive Mineralogy
- siliceous and/or calcareous rock
- high stiffness (low frac initiation pressure)
- relatively good reservoir quality

Conductive Mineralogy
- clay-rich (argillaceous) rock
- low stiffness (high frac initiation pressure)
- very poor reservoir quality

Siliceous zones
Pilot Hole Example – Lateral Placement

- Platform Express
- ECS SpectroLith & ELANPlus
- FMI image & interp
- Porosity, TOC, Perm & GIP

Optimized Target
Pilot Hole Example – Orienting the well

Drilling-Induced Fractures
- ENE-WSW
- Maximum horizontal stress

Natural Fractures
- ENE-WSW
- Important for natural completions
Bedding has high apparent dip and fractures have low apparent dip.

- Bedded Pyrite (conductive)
- Resistive Bed
- Open fractures (both induced and natural)
Horizontal Image Interpretation: Fracture Analysis

Drilling-Induced Fractures (2 types)
- form at the top and bottom of the hole
- typically do not cut across the entire wellbore

Longitudinal-Induced Fractures
- form when maximum horizontal stress is low and/or wellbore pressure is high
- orientation parallels the wellbore

Transverse-Induced Fractures
- form when minimum horizontal stress is low and/or a large weight on bit results in tensile failure
- very high dip magnitude (near-vertical)
- orientation parallels maximum horizontal stress

Natural Fractures
- typically cut the entire wellbore
- can be open (conductive), healed (resistive) or partially healed
- orientation and dip magnitude can vary
Stress Information in Horizontal Wellbores → Induced Fractures: Variable Characteristics = Variable Treatments

- Transverse & Longitudinal: Overall low stress & isotropic stresses
- Longitudinal only: Low maximum stress, high minimum stress (higher isotropic stress)
- Transverse only: Low minimum stress, Max >> Min stress (stress anisotropy)
- None: Overall high stress
Stress Information in Horizontal Wellbores → Induced Fractures: Variable Characteristics = Variable Treatments

- Short & wide fracture fairway

**Transverse & Longitudinal**
- Overall low stress
- isotropic stresses

**Longitudinal only**
- Low maximum stress, high minimum stress (higher isotropic stress)

**Completion considerations:**
- More spacing between perf clusters?
- More fluid for more frac length?
Stress Information in Horizontal Wellbores → Induced Fractures: Variable Characteristics = Variable Treatments

Transverse only

Low minimum stress,
Max >> Min stress
(stress anisotropy)

Completion considerations:
- Less spacing between perf clusters?
- Less fluid?
Stress Information in Horizontal Wellbores ➔ Induced Fractures: Variable Characteristics = Variable Treatments

No induced fractures

Overall high stress

Completion considerations:
- Closely spaced perfs?
- Isolation of high stress intervals?
Horizontal Woodford Example

Lithology Dependent Transverse Drilling Induced Fractures

Transverse DIF all around the hole in Chert Beds

Distance Transverse DIF travel around the hole is related to mineralogy. Infers large variation in stress between the layers.

No DIF in Clay Beds (except on bottom of hole – lower stress)
Impact of Mineralogy on Mechanical Properties and Stress

Overburden

Argillaceous Shale Bed
- $E_h = 5.9 \times 10^6$ psi
- $E_v = 3.1 \times 10^6$ psi
- $v_h = 0.261$
- $v_v = 0.246$

Cherty Shale Bed
- $E_h = 8.2 \times 10^6$ psi
- $E_v = 6.2 \times 10^6$ psi
- $v_h = 0.164$
- $v_v = 0.128$

Assume:
- $D = 7,500$ ft
- $P_r = 0.49$ psi/ft
- $\sigma_v = 1.10$ psi/ft
- $\alpha = 1.0$

Isotropic Stress
\[
\frac{v}{(1 - v)} \times (\sigma_v - \alpha P_r) + \alpha P_r
\]

Anisotropic Stress
\[
\frac{E_h}{E_v} \times \frac{v_v}{(1 - v_H)} \times (\sigma_v - \alpha P_r) + \alpha P_r
\]

Argillaceous Shale:
- Isotropic: $\sigma_h = 5.288$ psi = 0.705 psi/ft
- Anisotropic: $\sigma_h = 6,573$ psi = 0.876 psi/ft

Cherty Shale:
- Isotropic: $\sigma_h = 4.568$ psi = 0.609 psi/ft
- Anisotropic: $\sigma_h = 4,605$ psi = 0.614 psi/ft

Anisotropic shale properties increase stress in argillaceous intervals.

Large stress contrast between beds.
Barnett Example

For Comparison:
Lithology Independent Drilling
Induced Fractures in Barnett Shale
(Ft. Worth Basin)

Distance Transverse DIF travel around
the hole is independent of lithology

Much smaller Mechanical Properties Contrast
than in Woodford Shale
Natural Fractures: Variable Characteristics = Variable Treatments

Completion considerations:
- as natural fracture spacing decreases, perf spacing can increase
- isolate intervals with significant differences in natural fracture spacing

Fracture Spacing = 12.5 ft  No fractures  Fracture Spacing = 33 ft
Horizontal Image Interpretation Examples

- Drilling-enhanced, healed and open natural fractures
- Pyrite-lined bedding
- Longitudinal-induced fractures
- Transverse-induced fractures
- Drilling-enhanced, healed natural fracture
Horizontal Image Interpretation Examples

Sub-seismic faults

Potential Issues:
- wasted frac energy and inefficient reservoir stimulation
- can guide hydraulic fractures to water-bearing zones
Wrap Up: Completion Planning/Prediction Summary

Variable Characteristics = Variable Treatments

Mineralogy $\rightarrow$ reservoir quality, stiffness

Drilling-induced fractures $\rightarrow$ stress regime

Is a gamma ray log enough?

Natural fractures $\rightarrow$ system perm

Sub-seismic faulting

Hydraulic fractures from offset wells

Low gamma-ray concretions
Conclusions

✓ Geochemically-enhanced formation evaluation, advanced sonic measurements and/or borehole image analysis optimize horizontal well placement

✓ Borehole image and/or advanced sonic analyses define local stress regime and determine the optimal horizontal well azimuth

✓ Borehole image analysis can optimize the completion design
Thank You!