Slocombe-Rood #1-19

Results from a Hunton Horizontal Well

Unger Field, Marion County

Enhancing Oil Recovery from Mature Reservoirs Using a Lateral with Gamma Ray Sensor, Drillpipe Conveyed Well Logging Including Micro Resistivity Imaging

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John Doveton, David Newell
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Lawrence, KS 66006

Alan DeGood & Doug Davis
American Energy Corporation
Wichita, KS

Small Producer Project #07123-04
Outline

- Background
- Rig visit
- Pre-spud analysis
  - Stratigraphy, mapping
  - Well planning
- Actual well results
- 3D Visualization
- Concluding Remarks

Project Start: August 25, 2008
Project End: August 24, 2011
DOE Contribution: $248,385
Performer Contribution: $271,056
Contact Information:
RPSEA – Martha Cather (prrc.nmt.edu or 575-835-5685)
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University of Kansas – W. Lynn Watney (lwatney@ku.edu or 785-864-2184)
Background

• **Objective** –
  - Drill 1000 to 1500 ft lateral through porous Hunton dolomite residing at roughly 2800 ft MD
  - Section 19-Range 21 South- Range 4 East of Unger Field in Marion County, Kansas

• **Unger Field** –
  - Discovered in 1955 has produced 8.6 million barrels
  - 17 wells produced 16,191 bbls. in 2009, 2.6 BOPD per well

• **Wells on the Section 19 anticline originally produced several 1000’s of barrels of oil per day**
  - Wells average 2.6 bbls/day with high water cut (strong water drive)
  - Oil production can increase as wells pumped off suggesting oil still being drained outside of cone of depression

• **Lateral paralleled east flank of ¾ mile long northwest-trending anticline**
  - Local structural relief is 30 ft
  - Original oil column around 40 ft.

• **Porous Hunton reservoir**
  - Thickness ranges = 11-25 ft
  - Lithology – Dolomite - fractured, vuggy, intercrystalline Ø
  - Tight caprock above reservoir = 0-10 ft thick

• **The Hunton dolomite is overlain by a thick (~130 ft), relatively hard Kinderhook-Chattanooga Shale.**
  - Sufficiently hard rock for making turn of the lateral.
Horizontal Well
American Energies Corporation
Slocombe-Rood #1-19
Unger Field
Marion County, Kansas
Unger Field Production

Field discovery: 1955

Cum. 8.6 million bbls.

2009: 16,191 bbls., 17 wells
2.6 BOPD/well

Producing zones:
Hunton dolomite
~2800 ft (md)
Locally Misener Ss.
Partners in Unger Field Drilling

Design and well site supervision on over 300 horizontal wells drilled including multi-laterals in Oklahoma Hunton, Arbuckle, Barnett Shale and others – up to 8,000’ lateral displacement

Focus Gamma (sensor)
-- To avoid shale caprock above reservoir

Post Drill - Compact Micro Imager (CMI) & Triple Combo
(Gr, N-D Ø, Array Induction, Pe)

Use of modern to optimize selection of the completion interval
• Log-derived lithology, pore type,
• oil saturation, and fracture detection.
Project Website
http://www.kgs.ku.edu/PRS/Unger/index.html

Video in the making by Jeremy Viscomi, TORP
Presentation on horizontal wells to Fall Continuing Education Seminar, KBA-KIOGA:


15-103-20433-0100

Code on API number for horizontal & slant wells

HORIZONTAL WELLS IN KANSAS

<table>
<thead>
<tr>
<th>Total producing oil wells</th>
<th>238</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wells with oil production</td>
<td>20</td>
</tr>
</tbody>
</table>

Success rate (%) 8.4

<table>
<thead>
<tr>
<th>Formation</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Niobrara chalk shallow gas</td>
<td>61</td>
</tr>
<tr>
<td>Chase-Council Grove</td>
<td>10</td>
</tr>
<tr>
<td>Lansing-Kansas City</td>
<td>2</td>
</tr>
<tr>
<td>Cherokee CBM</td>
<td>15</td>
</tr>
<tr>
<td>McLouth Sandstone</td>
<td>9</td>
</tr>
<tr>
<td>Morrow-Chester</td>
<td>16</td>
</tr>
<tr>
<td>Mississippian carbonates</td>
<td>22</td>
</tr>
<tr>
<td>Viola</td>
<td>7</td>
</tr>
<tr>
<td>Arbuckle</td>
<td>8</td>
</tr>
</tbody>
</table>

October 2010
Productivity Improvement Factor

Distribution of Productivity in 96 horizontal wells

Average PIF = 2.5
Standard Deviation = 2.7

Joshi Technologies International, Inc.

PIF
C&G Drilling Rig, Eureka KS
C&G Drilling Rig #2, Geo trailer, Tres Management, Pan American Directional Drilling and MWD
January Field trip for students and industry with the boss
Alan DeGood, American Energies Corporation
John discussing MWD- azimuthal gamma ray tool
KGS colleagues and co-authors Jason Rush and Saibal Bhattacharyya with KGS Interim Director Rex Buchanan and DOE’s Brian Dressel
Geologist Doug Davis hard at work running samples
Strong show in Hunton - sucrosic, fine intercrystalline Ø dolomite with light brown spotty stain, free oil, fluorescence, cut, odor
Strong show in Hunton under ultraviolet light
Outline

- Rig visit
- **Pre-spud analysis**
  - Stratigraphy, mapping
  - Well planning
- Actual well results
- 3D Visualization
- Concluding Remarks
Two possible trajectories of the lateral
Green dashed – SW flank of structurally high
closer to fault and possible vertical water
conduit (dropped from consideration)
Purple dashed – NE side of structure

Section 19
Hunton isopach – south Unger Field

Geology by Gerry Honas

Actual Trajectory of the lateral - RED dashed – NE side of structure crossing rapidly thinning Hunton dolomite

Section 19
NW-SE structural cross section with scanned wells in sec. 19-21s-3w, Unger Field
Location of Lateral end:
1650 ft FNL & 1750 ft FWL
Open hole = 2100 ft

Lateral start: CNWSE
1878 ft FSL & 1750 ft FWL

Lateral bend:
2084 ft FNL & 2452 ft FWL

Section 19
Unger Field
Structure map top Hunton Group dolomite well trajectory

- Contour Interval = 5 ft
- Upper blue number = thickness of Hunton reservoir
- Original O/W ~-1420 ft

DST data from:
Slocombe 5, 6
Mellot 4
Rood 1, 2, 3, 4, 5, 7

Bottom hole pressure derived from DST
NW-SE Structural Cross Section #1

Target zone for lateral Paralleling cross section

900 ft

SP-Caliper-Microlog curves shown – SP depicted in color delimiting magnitude
Thickness of H3 layer with structure top of pay zone as contours
South to Northeast Structural Cross Section

- SP-Caliper-Microlog, neutron curves shown – SP (variable color) and neutron (all purple)
- Lateral passes through this cross section east of Rood #4

Tight upper section of Hunton reservoir
Near fault zone

Sweet Spot

Window of Lateral

~original O/W

Likely faulted zone

Vertical Exaggeration = 3x
Rood #4  se se nw 19 CAL-SP-Microlog
Effective ~14 ft.
Upper zone ~6 ft.

Good SP deflection (dashed line)
and mudcake (positive deflection of caliper – solid line)
suggest matrix permeable matrix porosity
NW-SE Structural Cross Section
with flow units (H1, H2, H3) of Hunton dolomite reservoir

American Energies Corporation
Rood    ANDERSON-PRICHARD OIL
      7    A-P Rood
      219  4  152
      0  109  0

Samson    E.W. Slocomb
      5  252
      36

Subsea Depth (ft)
-1340
-1345
-1350
-1355
-1360
-1365
-1370
-1375
-1380
-1385
-1390
-1395
-1400
-1405
-1410
-1415
-1420
-1425
-1430
-1435
-1440
-1445
-1450

H1
H2
H3

~original O/W

Lateral cuts cross section east of Rood #4

20 ft
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Horizontal Drilling Plan – Unger Field, Marion County, Kansas

American Energy Corporation
Unger Field

WELL PROFILE DATA

- MWD Info
- Azl TVD
- NIG
- E-W
- DLS
- Comment
- Date: 09-19-2010

1 inch = 500 ft
1137 ft.

Pan American Drilling Services, LLC

Actual 1137 ft.

1,700 ft lateral

Vertical Section on 320.0 deg azimuth with reference 0.00 N, 0.00 E
Azimuthal Gamma Ray ran while drilling to assist geosteering

Focus/azimuthal Gamma (sensor) -- To avoid shale caprock above reservoir and shale below reservoir

Drilling is paused while detector window on azimuthal gamma ray tool is rotated and measurements taken every 45 degrees through 360 degree rotation.
Ran Post-drill (drill pipe conveyed)

Compact™ Microimager (CMI)

Aux. Curves

CMI Dynamic Image

CMI Dips

CMI Static Image

1:120

Relative Bearing (HS)

Open_Fracture

Induced_Fracture

Partially_Open_Fracture

Breakout

Drilling_Induced_Fracture

Healed_Fracture

Fault

Enhanced_Fracture

Cross_Bedding

Bedding

Erosional_Bedding

Unconformable_Surface

Rosettes

Potato Plot

DYNAMIC IMAGE

Image Dips

STATIC IMAGE

18.83 ft
(5.70 m)

4.20 in.
(104.0 mm)

2.25 in.
(57 mm)

4.1 in.
(104.0 mm)

2.4 in.
(60.1 mm)

caliber at pads

Electronics section

Sonde section
Outline

- Rig visit
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- 3D Visualization
- Concluding Remarks
AMERICAN ENERGIES CORPORATION
COMPLETION RECOMMENDATION
Slocombe-Rood #1-19

LOCATION: NE SE NW SE Sec. 19-T21S-R3E
COUNTY: Marion
API: 15-115-21419-01-00
CONTRACTOR: C & G Drilling, Inc.
GEOLOGIST: Doug Davis

SURFACE CASING: 6 jts 9 5/8” set @ 256.01’
PRODUCTION CASING: 78 jts 7” set @ 3470’
PROJECTED RTD: 2815’, TVD: 4617’
G.L.: 1421’ K.B.: 1430’
SPUD DATE: 01/06/11

COMPLETION DATE:
TOTAL VERTICAL DEPTH: 2820’
TOTAL LATERAL DEPTH: 1137’
TOTAL HORIZONTAL DEPTH: 4613’

DST’S: None Taken
SAMPLE TOPS: None Taken
LOG TOPS: None Taken
LTD: 4613’

155 N. Market, Suite 710, Wichita, KS
316-263-5785, 316-263-1851 fax
Azimuthal Gamma ray with ROP

Directional Drilling Survey
MD, Inclination, Azimuth, TVD
Build & Turn

vertical section calculated along azimuth 319.4°
Directional drilling with Pason controls
Pason recording of drilling progress including gamma ray at bit at time enter Hunton dolomite in soft landing
Pason’s Real Time Drilling Data at Soft Landing
In Hunton Dolomite

1-17-11

Top Hunton 3396 MD, 2824 TVD, -1393 SS

Angle: current 88.05 degrees
Slope: 3.4 ft/100 ft
Length: 89 degrees
Position: x: y:
89 degrees (1.75 ft/100 ft)
MD vs TVD with location of lateral with respect to top and bottom of Hunton Pay

Projected Points to avoid sliding to change angle or inclination; decision made 10:45 am 1-20-11

- Slocombe 6
- A.P. Rood 2
- 88 degrees (3 ft/100 ft)
- sliding, cherty lith
- pump pressure 1500
- drilling slow, 3 ft/min
- (3 am 1-20)

Index numbers shown on following map
Finely crystalline sucrosic, intercrystalline Ø, poor light brown spotty stain, trace free oil, good fluorescence, cut, odor

Finely crystalline Ø, poor light brown spotty stain, free oil, fluorescence, cut, odor

Sucrosic, fine intercrystalline Ø, light brown spotty stain, free oil, fluorescence, cut, odor

Finely crystalline, no visible porosity, no to poor show, no free oil, fair fluorescence, cut, odor

Group 4
Depth-Constrained Clustering (Density and Neutron $\Phi$) & Pickett Plots (log $R_w$ vs. $\Phi$)

Group 1

Group 2

Ro = water wet line
Group 3

Likely pay

Run 4.5” tubing with slotted liner, set packers to produce between 3880 – 4060’

Group 4

Higher porosity, clustering of points ~ near irreducible, Sw = 40-60 %, min. BVW = 0.063. Excellent show
Lower $\Phi$, higher Sw, Along Ro => wet

Group 7
Run 4.5” tubing with slotted liners, set packers to produce between 3880 – 4060’
Interpretation of Weatherford’s Triple Combo and Electrical Micro Imaging (EMI) Log (fracture log)

Run 4.5” tubing with slotted liners, set packers to produce between 3880 – 4060’.

Dominate fracture set oriented NE
Water Saturation and Conductive (Open) Fractures

Group 4
### Pole Plot

<table>
<thead>
<tr>
<th>Bedding Planes</th>
<th>Fracture Planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schmidt Plot (3470.5-4554.5)</td>
<td>Modified Schmidt Plot (3470.5-4554.5)</td>
</tr>
</tbody>
</table>

#### CMI log Pole plot of fractures and bedding plans

- **Pole is perpendicular to plan that it is describing**
- **Open fractures primarily oriented E-NE**

**Open fractures**
Maximum Horizontal Stress

Western US Coalfield Stress Measurements

Illinois Basin US Coalfield Stress Measurements

Eastern US Coalfield Stress Measurements

general ENE-WSW maximum stress direction in central USA

Mark and Gadde (2010)
Maximum horizontal stress expected fracture directions

σ₁ is maximum horizontal stress direction
Horizontal Wells in a Fractured Reservoir
Idd El Shargi, Offshore Qatar

J. Rush, KGS
300 ft thick limestone reservoir with oil accumulation on broad structural trap

Laterals drilled from offshore platforms

Field produces ~135,000 BOPD

Idd El Shargi, J. Rush, KGS
Horizontal Targeting Arbuckle Paleokarst Wellington Field Data

*Concept for Upcoming Bemis-Shutts Lateral*
Outline

- Rig visit
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Conclusions

• Slocombe-Rood 1-19 a technical success

• Logging program permits optimization of completion design
  – *Selectively isolate high Sw zones/fractures*

• More experience = greater success

• Additional opportunities including horizontal injectors, multi-laterals, ...use of integrative technologies
Weatherford Completion team to run and set the packers and the liner.

- Isolate the 3880' to 4060'
- Pump until turns to a high water cut, then drop a ball to shutoff the first section
- Produce the second section from 3515' to 3880'.
- When this turns to a watercut similar to the first section, drill the ball out and produce the entire section 3515' to 4060'.
- The liner will only be set to 4280’ so this will be our plugged back TD.
- The hanger for the 4 ½” liner will be at 2900’ in the 7” production casing, meaning the 4 ½” liner will be set from 2900’ to 4280’.
- After the liner is set we will remove the 3 ½’ tubing above the liner and run 2 7/8’ tubing to 1500’ and install beam pump and pump from 1500’.
Producibility problems addressed with horizontal wells

- **Mature fields** – often have high water cut, strong water drive
- **Current production practice** – use conventional vertical wells
- **Limited lateral drainage in vertical well**
- **Significant variation in producibility** between adjacent wells
- **Residual pockets of oil** possibly located in the interwell areas outside the drainage reach of vertical wells
- **Often reservoirs are compartmentalized** (*karstification and subcropping strata*)
  - Wells located in small compartment have short production life, uneconomic cumulative volumes
  - Wells located (by chance) in large compartments – long production life
- **Effective pay zones in Kansas are thin** (*less than 20 ft*)
- **Limited resource-reach of operators** – financial and technical
History of Horizontal Wells

- Short Radius
- Medium radius, downhole motors, 1985
- Re-entry drilling, 1995
- Coil tubing drilling – underbalanced
- Rotary steerable system
- Fracture stimulation of horizontal wells

Horizontal Drilling in Kansas

Definitions & Terms

Common terms used to describe horizontal wells

Reservoir with Uniform Horizontal Permeability ($k_y/k_x = 1$)

Vertical Well
Drainage Area = 40 Acres
$x_{ev}/y_{ev} = 1$

Horizontal Well
Drainage Area = 100 Acres
$x_{eh}/y_{eh} = 2.5$
Horizontal Drilling in Kansas

Definitions & Terms

Common terms used to describe horizontal wells

VERITAL PROFILE: 332 NW

Kick Off Point

Bend
Radius in Ft.
Degrees / 100 Ft
Degrees / Ft.

Lateral Heel

Lateral Length

Lateral Toe

MWD - "Measurement While Drilling"
Azimuth, Inclination, Measured Depth

LWD - "Logging While Drilling"
mmost standard vertical hole e-logs

PIF - "Productivity Improvement Factor"
multiplier of production increase over offset vertical wells

Deepest
TVD: 2371 ft

MD: 4031 ft
TVD: 2364 ft

Gerlach (2000)
Multilaterals with conventional horizontal drilling technology

- Multibranching
- Forked
- Laterals into horizontal hole
- Laterals into vertical hole
- Stacked laterals
- Dual-opposing laterals
Additional cross section similar to section in previous slide

20 ft Lateral Target