Coal Seam Horizontal Drilling and Wellbore Design for Underground Coal Gasification

CCTR Advisory Panel

Indiana Center for Coal Technology Research

March 5, 2009
Jonathan Lightfoot
CBM & Shale Gas Business Development

Mechanical Engineer w/ Scientific Drilling for 12 Years

Experience Coalbed Methane Planning & Drilling Operations in the Arkoma, San Juan, Black Warrior, North Louisiana, Appalachian, WCSB (Canada) & Alaska CBM Drilling Areas
PRESENTATION OUTLINE

- SDI/SDC/ATA COMPANY INTRODUCTION
- COAL OVERVIEW
- UCG OVERVIEW
- WELL DESIGN OPTIONS
- INTERCEPT WELLS
- WELL DESIGN OPTIMIZATION CASE STUDY
- DIRECTIONAL DRILLING OVERVIEW
  - STEERING SYSTEMS
  - MEASUREMENT SYSTEMS
  - KEY ISSUES DRILLING IN COAL
  - LOGGING WHILE DRILLING SYSTEMS
- SUMMARY & RECOMMENDATIONS
Scientific is a Directional Drilling Service Provider that provides a very wide range of Wellbore Measurement & Navigation Systems

Diversified into Directional Drilling, MWD, Ranging, Drill Motors and Production Logging

Scientific is a company that custom builds all equipment, tools, sensors and instruments in-house
Company Structure

D. Van Steenwyk
Owner & CEO

ATA California (R&D)

Houston Headquarters

Adelaide Wineries

Scientific Drilling Inc.
USA
Operations in 10 States

Scientific Drilling Controls

Production / Cased Hole Logging

Canada
South America
Far East
Australia

North Sea
Scandinavia
Africa
Europe
FSU
Middle East
Company Structure

D. Van Steenwyk
Owner & CEO

ATA California (R&D)

- Our research and development arm
- Aerospace industry background
- Military - Navigation Systems
- Tool and Sensor Manufacture
- Software Development
- Product testing & Employee training center
ATA FACILITY

Paso Robles, R&D Office

Clean Room Manufacturing

Magnetics Lab

Gyro Lab
WORLDWIDE OPERATIONS

Existing facilities
EXPERIENCE

- Platform Drilling
- Deepwater Drilling
- Underbalanced
- Synthetic Muds
- Horizontal Drilling inc. underbalanced
- Reentries
- Bi-Center Bits / PDC Bits / Steerable Systems
- Casing Whipstock Sidetracks
- **Coal Bed Methane Horizontal Drilling**
- Shale Gas Horizontal Drilling
- Well control/intercept
- Geothermal wells
SDI HORIZONTAL EXPERIENCE

- Over 8,000 Onshore Wells North America in last decade

- >2,500 Horizontal Shale Gas projects (Barnett, Woodford, Caney....)

- >5,500 Coalbed Methane Horizontal Well Bores
COAL OVERVIEW
COAL IS UNIQUE: SOURCE ROCK & RESERVOIR 95% PURE METHANE

HOW COAL WAS FORMED

SWAMP 300 million years ago

Before the dinosaurs, many giant plants died in swamps.

WATER 100 million years ago

Over millions of years, the plants were buried under water and dirt.

Rocks & Dirt

Heat and pressure turned the dead plants into coal.
Factors Critical to Coalbed Natural Gas Productivity

- Gas Content
- Coal Rank
- Permeability
- Ground Water Flow
- Depositional Setting and Coal Distribution
- Tectonic and Structural Setting

Coalbed Natural Gas Producibility
COAL GAS STORAGE

ABILITY FOR A COAL TO STORE GAS
IT IS A FUNCTION OF:

- RANK (GRADE)
  - LIGNITE
  - SUBBITUMINOUS
  - BITUMINOUS
  - ANTHRACITE
- PRESSURE
- TEMPERATURE
**CBM – GAS CONTENT**

**GAS CONTENT OF COALS**

- Biogenic methane
- Nitrogen
- Carbon dioxide
- Thermally-derived methane
- Ethane and other hydrocarbons
- Volatiles driven off

**Gas content of coals**

- **LIGNITE**
  - Powder River Basin (<100)
- **SUB-BITUMINOUS**
  - San Juan Basin (100-500)
- **BITUMINOUS**
  - Raton Basin (200-400)
  - Ferron (Utah) (400)
  - Appalachian (200-400)
- **SEMI ANTHRACITE**
- **META**
- **GRAPHITE**

_after: Kim, 1978_

WHY IS COALBED METHANE CONSIDERED UNCONVENTIONAL?

- CONVENTIONAL COMPARED TO UNCONVENTIONAL

COMPARING CBM AND CONVENTIONAL NATURAL GAS DEVELOPMENT
Theoretical decline curve for a CBM well

- **Dewatering Stage**
- **Stable Production Stage**
- **Decline Stage**
- **Gas**
- **Water**

**Production Rate** vs **Time**

*From Schraufnagel, 1993*
METHANE PRODUCTION FROM COAL SEAMS

Water filled cleats keep methane trapped in micropores

Cleats—Fractures caused by drying of peat during coal formation

Methane moves to well bore after water is removed

Coal matrix blocks—contain micropores filled with methane
Basins > 200 billion tons

Coal areas of known or inferred extent
- Reported occurrences of small extent

Adapted from Landis and Weaver, 1993. "Hydrocarbons From Coal," AAPG. Areas are approximate. Basins labeled contain >200 billion tonnes.
TECHNICALLY RECOVERABLE COALBED METHANE GAS RESOURCES

GIP = CM_{coal mass} \times G_{as content}

CM_{coal mass} = Z_{coal zone thickness} \times A_{rea} \times D_{ensity}

TECHNICALLY RECOVERABLE RESOURCE?

10% OF GAS IN PLACE (GIP) IS ACCESSIBLE AND 50% IS THE RECOVERY RATE

SAN JUAN GIP 204 Tcf
TRR = 10.2 Tcf
US CUMULATIVE PRODUCTION (BCF)

- AUSTRALIA 1996 - 2005
- QUEENSLAND 166 BCF
- NSW 63 BCF
- TOTAL FOR AUSTRALIA – 266 BCF

By Basin to 12-31-06

13,147

San Juan 66%

Powder River 12%

Black Warrior 9%

Cent. Appal. 4%

Uinta 4%

Raton 625 3%

11 Small Basins

Arkoma 243
Cherokee 174
Piceance 41
N. Appalachian 20
Grtr Green River 18
Wind River 1
Gulf Coast 1
Hannah-Carbon <1
WY Thrust Belt <1
Alaska <1
Illinois <1

Total Cumulative CBM Production = 20,006 BCF Gas
US Coal Bed Methane Proved Reserves (BCF)
EIA-23, 2006

Total CBM Reserves = 19.6 TCF Gas
US Coalbed Methane Resources (TCF)

Potential Gas Committee, 2006

- Alaska: 35%
- American Pacific: 2%
- Gulf Coast: 2%
- Illinois: 5%
- Raton: 3%
- Cherokee + Arkoma: 3%
- 4-N Rockies Basins: 3%
- Uinta-Piceance: 3%
- 4-S Rockies Basins: 3%
- Southwestern: 4%
- Forest City: 4%
- Hannah-Carbon: 4%
- San Juan: 5%
- Black Warrior-Michigan: 11%
- Greater Green River: 2.5%
- Denver: 0.3%
- Black Mesa-Kaiapowits: 0.2%
- Wind River: 2.5%
- Big Horn: 0.8%
- Williston: 0.5%

Total CBM Resources = 157.9 TCF Gas
30,000 WELLS IN THE SAN JUAN

- FOCUS IS ON RECOVERY
- REDUCED WELL SPACING BELOW GROUND NOT AT SURFACE (PAD DRILLING)
- HORIZONTAL DRILLING
- CONSIDERABLE GAS STILL IN PLACE
- UCG POTENTIAL?

- OIL & GAS WELLS
- CBM WELLS
San Juan Basin

How do we know where hydrocarbons are located?
- Low gamma ray indicates a sandstone horizon or a shale.
- High resistivity indicates the pores in the rock contain hydrocarbons
- Low density indicates more porous sandstone instead of dense shale.

Perforate here!
## CBM Basin Comparison

<table>
<thead>
<tr>
<th>Coal Basin or Deposit</th>
<th>Coal Rank</th>
<th>Typical Depth (feet)</th>
<th>Typical Net Coal (feet)</th>
<th>Typical Gas Content (SCF/ton)</th>
<th>Typical Well Spacing (acres)</th>
<th>In-situ Density (g/cm³)</th>
<th>Avg. Well Production (Mcfd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois</td>
<td>Hvb/c</td>
<td>500</td>
<td>17</td>
<td>100</td>
<td>80</td>
<td>1.35</td>
<td>40</td>
</tr>
<tr>
<td>San Juan</td>
<td>Hvb</td>
<td>2,500</td>
<td>70</td>
<td>430</td>
<td>320</td>
<td>1.54</td>
<td>2,000-5,000</td>
</tr>
<tr>
<td>Black Warrior</td>
<td>Mvb</td>
<td>3,000</td>
<td>25</td>
<td>350</td>
<td>80</td>
<td>1.4</td>
<td>100</td>
</tr>
<tr>
<td>Central Appalachian</td>
<td>Mvb</td>
<td>2,000</td>
<td>16</td>
<td>n/a</td>
<td>80</td>
<td>n/a</td>
<td>120</td>
</tr>
<tr>
<td>Piceance</td>
<td>Hvb</td>
<td>5,500</td>
<td>80</td>
<td>768</td>
<td>40</td>
<td>1.35</td>
<td>140</td>
</tr>
<tr>
<td>Powder River</td>
<td>Sb</td>
<td>1,000</td>
<td>75</td>
<td>30</td>
<td>40-80</td>
<td>1.34</td>
<td>100-750</td>
</tr>
<tr>
<td>Uinta</td>
<td>Hvb</td>
<td>3,400</td>
<td>24</td>
<td>400</td>
<td>160</td>
<td>1.54</td>
<td>690</td>
</tr>
<tr>
<td>Arkoma</td>
<td>Hvb</td>
<td>2,200</td>
<td>6</td>
<td>250</td>
<td>n/a</td>
<td>n/a</td>
<td>50</td>
</tr>
<tr>
<td>Raton</td>
<td>Hvb</td>
<td>2,200</td>
<td>25</td>
<td>400</td>
<td>160</td>
<td>1.50</td>
<td>300</td>
</tr>
</tbody>
</table>
UCG OVERVIEW
UNDERGROUND COAL GASIFICATION

- Oxygen & Water Injected Into Horizontal
- Vertical Well produces raw Syngas
UNDERGROUND COAL GASIFICATION

- Underground Coal Gasification (UCG) is the *in situ* conversion of un-worked coal into a combustible product gas.
- The gas is suitable for industrial heating, power generation or hydrogen and natural gas production.
KEY FACTORS FOR ANY DRILLING PROGRAM

- SURFACE LOCATION RESTRICTIONS
- OFFSET WELLS (PROXIMITY & GEOLOGICAL CONTROL)
- COAL PROPERTIES – THICKNESS, DIP, PERM, ETC....
- ORIENTATION / DIRECTION OF CLEATS OR NATURAL FRACTURES
- PROXIMITY OF OTHER WATER-BEARING LITHOLOGIES
KEY FACTORS FOR ANY DRILLING PROGRAM

- STABILITY & QUALITY OF ROOF & FLOOR FORMATIONS
- WATER PRODUCTION & DISPOSAL REQUIREMENTS
- LEASE BOUNDARIES
- REGULATORY REQUIREMENTS – DRILL CUTTINGS, SAFETY, ROADS & INFRASTRUCTURE, ETC...
- GAS PRICE (METHANE, HYDROGEN & CO₂)
- GATHERING & PIPELINE CAPACITY
- UCG TO ELECTRICITY – REQUIREMENTS FOR POWER GENERATION
WELL DESIGN CONSIDERATIONS & OPTIONS
DIRECTIONAL WELL PROFILES

- Horizontal from Slant-Hole
- Slant Hole
- Short Radius
- Medium Radius
- Long Radius
- Horizontal Wells
- "HST" Sidetracking from Vertical or Deviated Well to Horizontal
- "Grass Roots" Stacked Laterals
- Opposing Horizontal Wells

SINGLE WELLS
MULTI-LATERAL WELLS
Figure 10  Multi-seam drilling for VCBM (Thompson et al)
VERTICAL vs. HORIZONTAL

- More footage of formation
- Increased cleat & fracture exposure
- Increased methane gas production!
- 4-10(x) Production
- 2(x) Total Well Cost
HORIZONTAL WELL TYPES

TYPES OF HORIZONTAL WELLS

- Categories of Horizontal Wells
  - LRH (LONG RADIUS)
  - MRH (MEDIUM RADIUS)
  - SHR (SHORT RADIUS)

- Horizontal classification in terms of build rates & type of wellbore
- Horizontal well design considerations
WHAT HOLE SIZE – INDUSTRY TRENDS

- TREND IS TO DRILL SMALLER CBM WELLBORES
- 4-3/4” FROM 5-1/2” RE-ENTRIES
- 4-3/4” GRASS ROOTS
- 4-3/4” IS BECOMING THE MOST COMMON, EXCEPT FOR ARKOMA
- GOOD WELLBORE STABILITY, SMALLER RIG, SMALLER FOOTPRINT, LESS IMPACT, HIGHER BUILD RATES, LESS $$$

Photo taken from: CO₂ Sequestration Potential of Texas Low-Rank Coals
W. B. Ayers, Jr., D. A. McVay, J. L. Jensen,
(Principal Investigators)
CURVE RADIUS

3-3/4" DRILL MOTORS: 4-3/4" HOLE
5-1/2" CSG HST

4-3/4" DRILL MOTORS: 6-1/2" – 6" HOLE

6-1/2" DRILL MOTORS: 8-3/4" – 7-7/8" HOLE
9-5/8" CSG HST

6-1/2" - 8" MOTORS & MOST ROTARY STEERABLES: 8-1/2” to >9-7/8” HOLE

<table>
<thead>
<tr>
<th>Build Rate °/100 ft</th>
<th>Hole Radius ft</th>
<th>Build Rate °/100 ft</th>
<th>Hole Radius ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2865</td>
<td>66</td>
<td>87</td>
</tr>
<tr>
<td>4</td>
<td>1432</td>
<td>68</td>
<td>84</td>
</tr>
<tr>
<td>6</td>
<td>955</td>
<td>70</td>
<td>82</td>
</tr>
<tr>
<td>8</td>
<td>716</td>
<td>72</td>
<td>80</td>
</tr>
<tr>
<td>10</td>
<td>573</td>
<td>74</td>
<td>77</td>
</tr>
<tr>
<td>12</td>
<td>477</td>
<td>76</td>
<td>75</td>
</tr>
<tr>
<td>14</td>
<td>409</td>
<td>78</td>
<td>73</td>
</tr>
<tr>
<td>16</td>
<td>358</td>
<td>80</td>
<td>72</td>
</tr>
<tr>
<td>18</td>
<td>318</td>
<td>82</td>
<td>70</td>
</tr>
<tr>
<td>20</td>
<td>286</td>
<td>84</td>
<td>68</td>
</tr>
<tr>
<td>22</td>
<td>260</td>
<td>86</td>
<td>67</td>
</tr>
<tr>
<td>24</td>
<td>239</td>
<td>88</td>
<td>65</td>
</tr>
<tr>
<td>26</td>
<td>220</td>
<td>90</td>
<td>64</td>
</tr>
<tr>
<td>28</td>
<td>205</td>
<td>92</td>
<td>62</td>
</tr>
<tr>
<td>30</td>
<td>191</td>
<td>94</td>
<td>61</td>
</tr>
<tr>
<td>32</td>
<td>179</td>
<td>96</td>
<td>60</td>
</tr>
<tr>
<td>34</td>
<td>169</td>
<td>98</td>
<td>58</td>
</tr>
<tr>
<td>36</td>
<td>159</td>
<td>100</td>
<td>57</td>
</tr>
<tr>
<td>38</td>
<td>151</td>
<td>105</td>
<td>55</td>
</tr>
<tr>
<td>40</td>
<td>143</td>
<td>110</td>
<td>52</td>
</tr>
<tr>
<td>42</td>
<td>136</td>
<td>115</td>
<td>50</td>
</tr>
<tr>
<td>44</td>
<td>130</td>
<td>120</td>
<td>48</td>
</tr>
<tr>
<td>46</td>
<td>125</td>
<td>125</td>
<td>46</td>
</tr>
<tr>
<td>48</td>
<td>119</td>
<td>130</td>
<td>44</td>
</tr>
<tr>
<td>50</td>
<td>115</td>
<td>135</td>
<td>41</td>
</tr>
<tr>
<td>52</td>
<td>110</td>
<td>140</td>
<td>40</td>
</tr>
<tr>
<td>54</td>
<td>102</td>
<td>145</td>
<td>38</td>
</tr>
<tr>
<td>56</td>
<td>100</td>
<td>150</td>
<td>36</td>
</tr>
<tr>
<td>58</td>
<td>99</td>
<td>155</td>
<td>35</td>
</tr>
<tr>
<td>60</td>
<td>95</td>
<td>160</td>
<td>34</td>
</tr>
<tr>
<td>62</td>
<td>92</td>
<td>165</td>
<td>33</td>
</tr>
<tr>
<td>64</td>
<td>90</td>
<td>170</td>
<td>32</td>
</tr>
<tr>
<td>Nominal Bit &amp; Wellbore Diameter</td>
<td>PDM Diameter</td>
<td>MWD &amp; LWD Tool Diameter</td>
<td>Lateral Push Drill Pipe</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------</td>
<td>-------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>4-3/4”</td>
<td>3-3/4”</td>
<td>3-1/2”</td>
<td>2-7/8” 10.4# S-135 Premium 2-7/8” AOH Drillpipe</td>
</tr>
<tr>
<td>6-1/4”</td>
<td>4-3/4”</td>
<td>4-3/4”</td>
<td>3-1/2” 13.3# S-135 Premium NC38 Drill Pipe</td>
</tr>
<tr>
<td>8-1/2”</td>
<td>6-1/2”</td>
<td>6-1/2”</td>
<td>4-1/2” 14# S-135 Premium NC46 Drillpipe</td>
</tr>
</tbody>
</table>
INTERCEPT WELL DESIGNS
Prior Well Design

Drilling a Horizontal Coalbed Methane Drainage System From a Directional Surface Borehole

By David C. Oyler and William P. Diamond
HORIZONTAL DOWNDIP INTERCEPT

- DOWNDIP HORIZONTAL ACCESS TO VERTICAL PRODUCTION
UCG-CSH END OF LATERAL INTERCEPT WITH THE MWD

CBM Horizontal to Vertical Intercept

80-160’
PASSIVE “MWD” MAGTRAC WELL INTERCEPT

CBM MagTrac Intercept – Dewater at the end of the lateral down dip

Re-Entry – Drill down hill to an existing well with a section milled in the desired interval.

Magnetic Raging Passive Intercept
WELL DESIGN OPTIMIZATION CASE STUDY
OPTIMAL WELL DESIGN?

- **FIVE HORIZONTAL WELL PROFILES ANALYZED**

Nikola Maricic, Chevron
Shahab D. Mohaghegh, WVU
Emre Artun, WVU

A Parametric Study on the Benefits of Drilling Multilateral and Horizontal Wells in Coalbed Methane Reservoirs

1. Total Horizontal Length (THL)
2. Spacing Between Laterals (SBL)
Conclusions

CBM recovery can significantly benefit from unconventional well configurations.

Considering a 320 acres of drainage area, the optimum configuration that the results of this study suggests is:

- Quadrilateral well configuration:
  SBL = 680 ft, and THL = 3,100 ft.

Time constant has a significant effect on the first year production, although it does not have a considerable effect on overall recovery.
3,100’ THL

680’ SBL
WEST VIRGINIA EXAMPLE

Field: MONONGALIA COUNTY, WV

<table>
<thead>
<tr>
<th>Name</th>
<th>TVD</th>
<th>+N/-S</th>
<th>+E/-W</th>
<th>Northing</th>
<th>Easting</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEST TD</td>
<td>966.00</td>
<td>4820.60</td>
<td>-505.69</td>
<td>440440.88</td>
<td>1754162.34</td>
<td>Rectangle (3800x200)</td>
</tr>
<tr>
<td>CENTER TD</td>
<td>966.00</td>
<td>4564.57</td>
<td>1909.68</td>
<td>440101.22</td>
<td>1755574.50</td>
<td>Rectangle (3900x200)</td>
</tr>
<tr>
<td>SC13A INTERCEPT</td>
<td>966.00</td>
<td>428.52</td>
<td>145.19</td>
<td>435982.49</td>
<td>1754769.97</td>
<td>Circle (Radius: 1)</td>
</tr>
<tr>
<td>EAST TD</td>
<td>966.00</td>
<td>3369.88</td>
<td>3543.31</td>
<td>438890.73</td>
<td>1755196.48</td>
<td>Rectangle (3881x200)</td>
</tr>
</tbody>
</table>

Plot Date: 4/24/2007
By: Carl Bakay
Scientific Drilling, Inc.
800-679-7302
carl.bakay@scientificdrilling.com

SITE DETAILS
SC-13A WELL LOCATION
Monongalia County, WV

Site Centre Northing: 435,555.40
Easting: 1,754,620.63

Ground Level: 1203.65
GL + 6 RKB: 1213.65
Convergence: -0.58

Vertical Section at 51.83° [600ft/in]
NORTHERN APPALACHIAN OPERATIONS
### Target Details

<table>
<thead>
<tr>
<th>Name</th>
<th>TVD</th>
<th>+N/S</th>
<th>+E/W</th>
<th>Northing</th>
<th>Easting</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAST 1 TD</td>
<td>910.00</td>
<td>1794.94</td>
<td>3253.94</td>
<td></td>
<td></td>
<td>Rectangle (3044x200)</td>
</tr>
<tr>
<td>EAST 2 TD</td>
<td>910.00</td>
<td>1189.94</td>
<td>2825.58</td>
<td></td>
<td></td>
<td>Rectangle (1693x200)</td>
</tr>
<tr>
<td>GH29 INTERCEPT</td>
<td>910.00</td>
<td>211.85</td>
<td>296.45</td>
<td></td>
<td></td>
<td>Circle (Radius: 1)</td>
</tr>
<tr>
<td>WEST 1 TD</td>
<td>910.00</td>
<td>2592.42</td>
<td>1131.45</td>
<td></td>
<td></td>
<td>Rectangle (1735x200)</td>
</tr>
<tr>
<td>WEST 2 TD</td>
<td>910.00</td>
<td>2327.17</td>
<td>2171.86</td>
<td></td>
<td></td>
<td>Rectangle (2452x200)</td>
</tr>
</tbody>
</table>

### Section Details

<table>
<thead>
<tr>
<th>Sec</th>
<th>MD</th>
<th>Inc</th>
<th>Azi</th>
<th>TVD</th>
<th>+N/S</th>
<th>+E/W</th>
<th>D Leg</th>
<th>T Face</th>
<th>V Sec</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1383.89</td>
<td>90.00</td>
<td>51.13</td>
<td>910.00</td>
<td>337.36</td>
<td>452.16</td>
<td>0.00</td>
<td>0.00</td>
<td>550.14</td>
<td>WEST 2 TD</td>
</tr>
<tr>
<td>2</td>
<td>1561.45</td>
<td>90.00</td>
<td>40.48</td>
<td>910.00</td>
<td>460.96</td>
<td>579.28</td>
<td>6.00</td>
<td>90.00</td>
<td>726.68</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4014.82</td>
<td>90.00</td>
<td>40.48</td>
<td>910.00</td>
<td>2327.17</td>
<td>2171.86</td>
<td>0.00</td>
<td>0.00</td>
<td>3180.06</td>
<td></td>
</tr>
</tbody>
</table>

### Site Details

Scientific Drilling
Directional Drilling Operations

GREENE COUNTY, PA

Site Centre Northing:
East of:

Ground Level: 1129.13
GL + RKB: 1137.13
Convergence: -1.67
Single Bit Cumulative Footage Drilling Records with Insert Bits

Mountaineer Operations (CBM)

- In 2007, drilling time was lowered from 21 days to 15 days with an improved well design.
- In 2008, the use of near-bit gamma detectors could further lower drilling time from 15 to 12 days.

CNX Gas reservoir engineers designed an asymmetric quad pattern in 2007.

Mountaineer Operations set three world records for horizontal drilling with a single drill bit (per Smith International).
COMPONENTS OF DIRECTIONAL STEERABLE SYSTEMS
DRILL STRING / BHA

DIRECTIONAL DRILLING EQUIPMENT

- Drill Bit
- Positive Displacement Drill Motor
- MWD System (MP or E-Field)
- Logging While Drilling Tool
- Non-Magnetic Collar
- Push Drill Pipe or Collars
- Heavy Weight Drill Pipe
- Drill Pipe from Surface
COALBED METHANE HORIZONTAL OPERATIONS - DRILL BIT SELECTION

Tri-Cone Bit

Tri-Cone and PDC Bits

PDC Bit

[Image of a Tri-Cone Bit and PDC Bit]
CURRENT DIRECTIONAL NAVIGATION DRILLING SYSTEMS

(DEFLECTION / STEERING)
DIRECTIONAL DRILLING CURRENT SURVEY & DIRECTIONAL STEERING METHODS

BENT HOUSING DRILL MOTOR

GENERIC HYBRID ROTARY STEERABLE
POSITIVE DISPLACEMENT MOTOR (BENT HOUSING)

(Courtesy Robbins & Myers, Inc)

(Courtesy Scientific Drilling)
Methods of Deflection

Fluid under high pressure

Cavity formed between Rotor and Stator

Fluid at low pressure

Cavity formed between Rotor and Stator

Fluid at low pressure

Cavity formed between Rotor and Stator

Fluid at low pressure
Methods of Deflection

INCREASING TORQUE

INCREASING RPM
BUILD RATE PREDICTION

- HOLE SIZE
- FORMATION
- BIT TYPE
- FLOW RATE
- DIFFERENTIAL PRESSURE
- WEIGHT ON BIT
- BIT HYDRAULICS
- BEND SETTING
- BIT TO BEND DISTANCE
- STABILIZATION
- SLIDE PERCENTAGE (FOOTAGE SLIDING VS. ROTATING)
CURRENT DIRECTIONAL MEASUREMENT SYSTEMS

MWD – MEASUREMENT WHILE DRILLING
MEASUREMENT SYSTEMS (INC & AZ)

- WELLBORE NAVIGATION & MEASUREMENT
  - WIRELINE STEERING & ORIENTATION SYSTEMS
    - CONVENTIONAL FILM BASED GYRO MULTI & SINGLE SHOT TOOLS
    - CONVENTIONAL FILM BASED MAGNETIC SINGLESHOT TOOLS
    - ELECTRONIC W/L STEERING TOOLS ("MWD ON WIRELINE")
    - NORTH SEEKING RATE GYROS

- MWD SYSTEMS
  - MUD-PULSED (POSITIVE OR NEGATIVE PULSE) MWD
  - E-FIELD (ELECTROMAGNETIC) MWD
  - gMWD (E-FIELD or MUD-PULSED)
MWD FLUID PULSE DATA TRANSMISSION

Positive Pulse Telemetry

Continuous Wave Telemetry

Negative Pulse Telemetry
E-Field MWD Instruments

Electromagnetic MWD uses radio waves

Works in compressible fluids (underbalanced)
E-FIELD MEASUREMENT WHILE DRILLING

- ELECTROMAGNETIC MWD ILLUSTRATION
ELECTROMAGNETIC MWD FEATURES

Features

- Inclination
- Azimuth
- Toolface (highside + magnetic)
- Vibration (peak, average & RMS)
- Gamma (optional)
- Focused Gamma (optional)
- GAIN (Gamma Inc)
- Pressure While Drilling (PWD)
- Annular-Pipe-Differential
- Long Wire
- Softride Collars (Air Drilling)
- Wi-Sci “Short Hop” communication to additional tools, i.e. Smart Motor, SRX, Bit Subs, etc...

- NOW WITH KEEPER GYRO SERVICES
MP & E-Field MWD SYSTEMS
COLLAR AND HOLE SIZES
SDI - ONE SIZE MWD FOR ALL HOLE SIZES

5-7/8” THRU 7-7/8”

7-7/8” THRU 9-7/8”

12-1/4” or 9-7/8”

4-3/4” THRU 5-7/8”

7-7/8” THRU 8-3/4”

8-1/2” THRU 9-7/8”
MWD – RETREIVABLE SYSTEMS

RETRIEVABLE OPTIONS

- RUBBER FINNED CENTRALIZERS
- BOW-SPRING CENTRALIZERS
MWD PROBE BEING PICKED UP
RETRIEVABLE E-FIELD MWD SYSTEM

EM3 E-Field
Bottom-Landed — Retrievable

IPL 726A

Rev. 1.2
Page 1 of 4
Jan 2006

Rev. 1.2
Page 2 of 4
Jan 2006
KEY ISSUES DRILLING IN COAL
KEY ISSUES

Maintaining the BHA heading within the Target Zone – Thick Seams are sometimes More difficult to drill in zone because the BHA is prone to get out of plane with the formation

Too high

Too low

12 - 20 ft
KEY ISSUES

Maintaining the BHA heading within the Target Zone – Thin Seams are sometimes easier to drill in zone because the BHA tends to deflect off the roof and floor of the coal seam and stay in plane with the formation.
HORIZONTAL KEY DRILLING ISSUES

Drilling a Horizontal Coalbed Methane Drainage System From a Directional Surface Borehole

By David C. Oyler and William P. Diamond

FIGURE 19. - Two methods of following the coalbed. Method B is recommended.
CSH KEY DRILLING ISSUES

FAULTING AND FRACTURING

Possibility of steering up into another coal seam

Sandstone

Upper Coal Seam

Under Clay

Middle Coal Seam

Sandstone

Lower Coal Seam

Shale
CSH KEY DRILLING
ISSUES

FAULTING AND FRACTURING

Pick Coal Seam from Offset well near planned lateral

Landed low, steer up, find seam and drill lateral

Cross fault and drill out of the seam, decide to steer down b/c of data from offset well

Set Coal Seam Landing Point based on estimated bed dip.
CURRENT COAL LATERAL LOGGING WHILE DRILLING TECHNOLOGY

LWD – GAMMA RAY

RADIAL, FOCUSED (SHIELD) NATURALLY FOCUSED (LWDM)
The gamma tool measures naturally occurring radiation, rather than induced gamma rays from a source, such as in the density tool.

These natural gamma rays emanate from radioactive elements contained in sedimentary formations, mainly potassium (K), thorium (Th), and uranium (U).

Potassium and thorium are closely associated with the presence of clay minerals in shale (illite, kaolinite, and montmorillonite), while uranium may be found in sands, shales, and certain carbonates.

The gamma tool provides an excellent indicator of the presence of shale.
Focused Gamma module as part of the Efield MWD Navigation package behind the motor assembly.

By the rotation of the tool string behind the motor with the focused gamma, the boundary of the coal seam is evaluated and the course corrections are made to stay in the zone.
FOCUSED & ORIENTED GAMMA RAY
E-FIELD CSH LWD CONFIGURATION

1. Radial Gamma Ray Assembly
   (1x4” or 5/8x3” Crystal)

2. Internally Focused Gamma Ray Assembly

3. Externally Focused Gamma Ray Assembly

30 Inch Extension Assembly
Wi-Sci Moves Sensors Closer to the Bit

Standard MWD
inclination
focused gamma?

TOO LATE!

Smart Motor
with Wi-Sci
Technology

Inc & Focus Gamma
Reducing Bit to Sensor Distances

MWD/LWD SENSORS 42’+ f/ Bit

Gamma & Inc.
30’

MWD 42’ f/ Bit

LWDM
Gamma & Inc. - 5’

MWD 42’ f/ Bit

STANDARD
MWD/LWD

EXTENDED
GAIN LWD

SMART
MOTORS
(LWDM)
Focus Gamma Ray & Inclination 60” above the drill Bit!

LWDM Log While Drilling Motor
(Focused Gamma & Inclination Measurements)
Focus Gamma Ray & Inclination 60” above the drill Bit!
ELECTROMAGNETIC MWD – SHORT HOP
By the rotation of the tool string behind the motor with the focused gamma, the boundary of the coal seam is evaluated and the course corrections are made to stay in the zone.

Focused Gamma module as part of the LWDM (Logging While Drilling Motor) - Navigation payload in the motor assembly drive assembly.
LWDM SENSOR CONFIGURATION

- GAMMA RAY – NATURALLY FOCUSED / ORIENTED
- INCLINATION
- VIBRATION
- TEMPERATURE

Sensor Electronics

Stackable Smart Battery Packs

Smart Battery & Wi-Sci Telemetry Electronics
New Technology Development

MWD “Short Hop” data transmission & Motor Development for Slim Hole CBM

Smart Motor measures Gamma Ray increase before the Radial Gamma
KEY CHALLENGE – DECIDE THE BEST APPROACH FOR THE SPECIFIC PROJECT

- WILL PROVEN CBM DRILLING TECHNIQUES APPLY TO UCG GAS WELL DESIGNS?
  - POSSIBLY
  - SOME TECHNOLOGY MAY WORK
  - USE SOUND DRILLING PRACTICES
  - EARLY ON, MINIMIZE YOUR RISK

- RECOMMENDATION
  - BE PREPARED TO TEST DIFFERENT DRILLING & COMPLETION TECHNIQUES TO FIND THE OPTIMAL SOLUTION
  - WHAT WORKS IN COLORADO OR OKLAHOMA CBM MAY NOT WORK IN ALL UCG APPLICATIONS
  - BE READY TO EXPERIMENT, MINIMIZE YOUR RISKS & WORK REALLY HARD TO ESTABLISH DESIGNS THAT WORK BEST FOR EACH LOCAL AREA
  - PLAN WELLS TO MAXIMIZE YOUR ACREAGE AND MINIMIZE IMPACT TO THE ENVIRONMENT
SUMMARY & RECOMMENDATIONS

- Use in UCG what has been successful in CBM Horizontal Drilling

- Have a Team Approach & Keep the Team Consistent

- Make a detailed plan but be flexible

- Maximize wellbore stability by drilling a smaller wellbore diameters

- Use the best “fit for purpose” drilling tools

- Promote the development of new tools and methods to help drill a higher percentage coal footage
GENERAL DISCUSSION & QUESTIONS