Rotliegend
„Tight Gas“
Field Leer (Ostfriesland)
Germany

A Development with a
Multiple Hydraulically Fractured
Horizontal Well: Project Leer Z4

Michael Koehler

Symposium “Tight Gas Fields”,
EBN and TNO Geo-Energy,
September 19th, 2006, Utrecht, The Netherlands

Outlines

- Gas Field Leer: General Introduction

- Project Leer Z4: Multiple Fractured Horizontal Well
  - Drilling
  - Well Completion
  - Perforation
  - Stimulation
  - Well Cleanup and Tracer Investigation

- Conclusions
  - General
  - Positive Experiences
  - Negative Experiences
Geological Basemap: NW-German and NE-Dutch Gas Fields
Leer structure is located on the southern margin of the Permian Basin (Rotliegend, Wustrow- and Bahnsen-Member).

Depositional Setting: Desert plain: Dominated by aeolian dunes, dry sandflats, and damp sandflats with occasional presence of deposits of wet sandflats and aeolian mudflats.

Proximal channels with coarse deposits with claystone intraclasts and channels (less mature composition). Sheetfloods and lake deposits.

The reservoir can be sub-divided into five drying upward cycles.

Sub-units are assumed to be climatically driven by lake base level and ground water table fluctuations. Subsequent lateral move of facies belts.

$k_v/k_h = 1/10$ vertical barriers and lateral facies boundaries → Risk: Compartmentalization.
Ostfriesland: Rotliegendes
Core Permeability (in situ (pws=680 bar(a) @4350 m TVD b. SS), pre de-salted)

In-situ Permeability Distribution from Core Data:
Leer Z2-Z3a and other Ostfriesland Wells
Leer Z4: Drilling Path and Project Target
West-East-Cross-Section: Structure Leer
Cross-Section on the Base of PreSDM Seismic ( Depths)
LEER Z4 Block: Zechstein/Rotliegend
Length and Width:
N/S: 3.9 km x E/W: 1.2 km
Area: 4.7 km²

Structural Dip: 4.5° ENE

Ref. Depth: 4420 m TVDss

Reservoir Pressure: 680 bar

Temperature: 150 °C

Gross Thickness: 78 m

Net Thickness: 45 m

Porosity: 9.7%

Water Saturation: 34%

Permeability: 0.020-0.150 mD

FWL : 4464 m TVDss
GWC: 4450 m TVDss

OGIP (P90, P50, P10): 3050, 4300, 5600 Mio. m³(Vn)
**LEER Z2: 1971**
Gas Rate = 1500 - 1000 m³/(Vn)/h
@WHFP = 8 - 5 bar
Permeability = 0.020 mD
OGIP = 5 Mio. m³/(Vn)

**LEER Z3: 1978**
Gas Rate = 1000 - 1500 m³/(Vn)/h
@WHFP = 266 - 224 bar
Permeability = 0.050 mD
OGIP = 150 - 200 Mio. m³/(Vn)

**LEER Z3a (post frac): 1998**
Gas Rate = 9 500 m³/(Vn)/h
@WHFP = 440 bar
Permeability = 0.150 mD
OGIP = 530 - 600 Mio. m³/(Vn)

**LEER Z4: 2005**

Field History: Well History & Test Results
LEER Z4: Well Path:
W-E-Cross Section of Leer the Structure
Leer Z4: Seismic Section vs. Geomodel Reservoir Section
Successful application of LWD-tools

Estimation of fracture positions based on logging results → Influenced by: Sub seismic faults and compartments.

Optimum number of fracture stimulations: Local conditions, numerical simulation and literature.

Limited access: short perforation length

Result: Well Path (WU) = 680 m AH, Frac Distance = 155 m, Net-Thickness = 328 m AH, Porosity = 11.1%, Water Sat. = 31.9%, 3 Compartments (cutoffs: Phi>= 9%, Sw< 50%)

LEER Z4: Cross Section : W-E - Well Path with GR- and Porosity-Log together with Frac-Positions
Influence of Perforation Sections on Frac-Initiation ($D_w =$ Well Bore Diameter)

Reference:
El-Rabaa (1989): SPE 19 720
(from Soliman (2004): SPE 86 992)

El-Rabaa: $L(\text{Perfo}) \leq 4 \times D_w(\text{max})$

Soliman: $L(\text{Perfo}) \text{ ca.} 0.2 \text{ ft} = 0.6 \text{ m}

Perforation: $3 \frac{1}{8}''$ big holes
Case with 3, 4 to 6 effective Perfo Tunnels

$135^\circ/45^\circ$- Phasing,
10 SPF: 8 Shots/ $360^\circ$
20 Perforations / 2 ft
$d(\text{Perfo, hole}) = 0.69'' = 17.5 \text{ mm}$

Expected Fracture Initiation and Propagation based on a $3 \frac{1}{8}''$ Perforation Gun
\[ \Delta p_{Perfo} = C_1 \cdot q_{Injection}^2 \cdot \rho_{fluid} / \left( n_{Perfo}^2 \cdot C_d^2 \cdot d_{Perfo}^4 \right) \]

**Perforation Pressure Loss for limited Entry Fracture Treatment**

Based on sharp-edged orifice equation (Romero SPE 63009 and Shah, GRI-Paper)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Low Case</th>
<th>Most Likely</th>
<th>High Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole Diameter</td>
<td>d(hole)</td>
<td>inch</td>
<td>0.56</td>
<td>0.56</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mm</td>
<td>14.2</td>
<td>14.2</td>
<td>14.2</td>
</tr>
<tr>
<td>Phasing</td>
<td>Deg.</td>
<td></td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Holes/360°</td>
<td></td>
<td></td>
<td>1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Perforation Length</td>
<td>L(Perfo)</td>
<td>inch</td>
<td>1.87</td>
<td>1.87</td>
<td>1.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mm</td>
<td>47</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>Effective Number of Holes</td>
<td>N(holes)</td>
<td></td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Fluid Density</td>
<td>Rho(fluid)</td>
<td>kg/m³</td>
<td>1 040</td>
<td>1 040</td>
<td>1 040</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lb/gal</td>
<td>8.68</td>
<td>8.68</td>
<td>8.68</td>
</tr>
<tr>
<td>Injection Rate</td>
<td>q(injection)</td>
<td>m³/min</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>m³/min</td>
<td>25.16</td>
<td>25.16</td>
<td>25.16</td>
</tr>
<tr>
<td>Injection Rate per Hole</td>
<td></td>
<td></td>
<td>8.39</td>
<td>6.29</td>
<td>4.19</td>
</tr>
<tr>
<td>Proppant Quantity</td>
<td>m(Prop.)</td>
<td>tons</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lbm</td>
<td>264 555</td>
<td>264 555</td>
<td>264 555</td>
</tr>
<tr>
<td>Discharge Coefficient</td>
<td>Cd</td>
<td>psi</td>
<td>1 856</td>
<td>1 044</td>
<td>464</td>
</tr>
<tr>
<td>Perforation Pressure Drop</td>
<td>D(p,perfo)</td>
<td>bar</td>
<td>128</td>
<td>72</td>
<td>32</td>
</tr>
</tbody>
</table>

**Big Hole with 3 1/8”-Gun 10 SPF Perforation 20 holes/2 ft**

**LEER Z4:**
Expected Perforation Friction
Remarks
- All fracture fluids will be marked with fracture individual tracers

1. Breakdown
- Initiation of a fracture
- Stable fracture propagation

2. Step Rate Down Test 1
- Estimation of near well bore friction (perforation and tortuosity)
- Estimation of effective numbers of perforations (min. 3 - 4 „big holes“)

3. Shut-in
- ISIP, fracture closure and reservoir pressure

4. Mini Frac
- Creation of a x-linked fracture
- Modelling of fracture propagation
- Leak-off behavior, erosions with x-linked gel and low conc. proppant stage (1 - 3 ppg)

5. Step Rate Down Test 2
- Analog Step Rate Down Test 1
- Recognition of differences

6. Main Frac
- Based on the previous examinations

Principle Treatment Schedule:
Data Frac 1 (Breakdown & SRDT 1) → Mini Frac → Data Frac 2 (SRDT 2) → Main Frac
LEER Z4: Data Frac 1: Breakdown Step Rate Down Test from Frac 4

Formation Breakdown Near Well Bore Friction effective Perforation

Frac-Dimensions

Top Wustrow Sandstein

Perfo

Fracture Half Length

Near Well Bore Friction

Model Perforation Drop Friction

Model Tortuosity-Related Friction

Tortuosity

Totals

Perforation

Pump Rate in m³/min

Depth (m) Stress Profile (bar) Width (cm)

Observed Fric B=1.32

Depth 4440 4431 4422 4413 4404 4395 4387 4378 4369

Top Wustrow Sandstein

Frac-Dimensions

Step Rate Down Test

BHP

Fluid Efficiency

Slurry Rate

WHP

Time

Slurry Rate

Tubing Treatment Press

BHP from WB Model and/or Data

Fluid Efficiency

1000 800 600 400 200 0

5 4 3 2 1 0

1000 840 680 520 360 0

0.8 0.6 0.4 0.2 0

10 8 6 4 2 0

1000 840 680 520 360 0

0.5 0.4 0.4 0.4 0.4 0

Step Rate Down Test

Frac-Dimensions

Fluid Efficiency

Slurry Rate

WHP

Time
LEER Z4: Mini Frac:
Example: Frac 4

- Design of PAD volume to access securely the vertical fracture height.
  Investigation of erosion potential with x-linked gel and low concentrated proppant slugs.

- 1-2 slugs (prop. conc.: 1-3 ppg – 120-360 g/l). Slug stages are placed to be effective after stabilization of fracture propagation.

- If two proppant slugs are pumped a sufficient buffer of x-linked gel is essential.

- General Leer problem: To initiate a fracture from a high stress regime to a low stress regime → low fracture width @perforation.
### LEER Z4: Fracture Treatments - Friction Results

<table>
<thead>
<tr>
<th>Frac</th>
<th>Treatment</th>
<th>Perforation Friction</th>
<th>Tortuosity</th>
<th>total Friction</th>
<th>Ratio on total Fric.</th>
<th>Perforation</th>
<th>effective Pero.</th>
<th>Number of Perf.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SRDT</td>
<td>180</td>
<td>47</td>
<td>227</td>
<td>21%</td>
<td>79%</td>
<td>4</td>
<td>20%</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>SRDT 1</td>
<td>95</td>
<td>93</td>
<td>188</td>
<td>49%</td>
<td>51%</td>
<td>3</td>
<td>4</td>
<td>20%</td>
</tr>
<tr>
<td>2</td>
<td>SRDT 2</td>
<td>51</td>
<td>61</td>
<td>132</td>
<td>61%</td>
<td>39%</td>
<td>4</td>
<td>4</td>
<td>20%</td>
</tr>
<tr>
<td>3</td>
<td>SRDT 1</td>
<td>227</td>
<td>18</td>
<td>245</td>
<td>7%</td>
<td>93%</td>
<td>2</td>
<td>3.7</td>
<td>15%</td>
</tr>
<tr>
<td>3</td>
<td>SRDT 2</td>
<td>60</td>
<td>69</td>
<td>129</td>
<td>53%</td>
<td>47%</td>
<td>3</td>
<td>5.3</td>
<td>20%</td>
</tr>
<tr>
<td>4</td>
<td>SRDT 1</td>
<td>108</td>
<td>25</td>
<td>133</td>
<td>19%</td>
<td>81%</td>
<td>2</td>
<td>4.5</td>
<td>20%</td>
</tr>
<tr>
<td>4</td>
<td>SRDT 2</td>
<td>81</td>
<td>41</td>
<td>122</td>
<td>34%</td>
<td>66%</td>
<td>3</td>
<td>4.5</td>
<td>20%</td>
</tr>
<tr>
<td>5</td>
<td>SRDT</td>
<td>144</td>
<td>45</td>
<td>189</td>
<td>24%</td>
<td>76%</td>
<td>7</td>
<td>12</td>
<td>30%</td>
</tr>
</tbody>
</table>

**LEGEND:**

| SRDT 1 = Step Rate Down Test before Mini Frac. |
| SRDT 2 = Step Rate Down Test after Mini Frac. |

- High perforation friction before Mini Frac, even with „big holes“.
- Significant lower perforation friction after Mini Frac, due to erosion (x-linked gel and proppant slugs).
- Tortuosity is relatively low: Transverse fractures are expected (suitable well direction: ENE)

**Observed perforation friction and tortuosity**

LEER Z4: Comparison: Data Frac 1 und 2 of Frac 2 to Frac 4
Breakdown volume must be scheduled to reach a stable vertical fracture status, where a step rate down can be performed.

The Mini Frac must be designed to reach the main vertical sequence and thus to examine the vertical stress profile. 1 slug test from 1-3 ppg should be sufficient.

A step rate down test post Mini Frac should be performed as a standard to investigate the curability of the NWB friction.
- Pad volume according to stress profile and fracture dimensions, optional with slug stages.
- Smooth enhancement of proppant concentration to reach the first plateau phase with relatively constant proppant concentration.

- Plateau @6 ppg: Begin “on the fly”-coating @50% proppant quantity.
- Smooth transfer to the next plateau.
- Plateau @8 ppg
- Tail of treatment: Problem with limited number of perforations ➔ Screenouts can occur.

LEER Z4: Main Frac:
Example: Frac 4
September 19th, 2006: Slide: 22/30

Frac 2: 88.1 t
Frac 3: 113.2 t
Frac 4: 135.2 t
Frac 5: 1.5 t
Frac 1: 69.4 t

All fractures are shown with the same fracture conductivity kf*wf scale in mD.m @Fracture damage factor = 50%.

Trend – Reservoir Parameter

Top Wustrow

Porosity

Frac 1
Frac 2
Frac 3
Frac 4
Frac 5

bad
better

Target fracture conductivity

LEER Z4: Main Fracture Comparison: Frac 1 to 5

Trial with composite plugs: Temporarily plugged off with: Sand plug

Plugged-off with: Sand plug

Plugged off: Sand plug "auto-cleanout" forced to set a new separate sand plug

Sandout = Sand plug
**LEER Z4: General Fracture Treatment Data**

<table>
<thead>
<tr>
<th>Frac</th>
<th>Treatment</th>
<th>Clean Volume $m^3$</th>
<th>PAD $m^3$</th>
<th>Slug</th>
<th>100-Mesh Sand tonnes</th>
<th>Pumped Proppants tonnes</th>
<th>Formation Proppants tonnes</th>
<th>Sandout tonnes</th>
<th>final BH Prop. Conc. ppg</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mini Frac</td>
<td>195.94</td>
<td>26</td>
<td>two Slugs</td>
<td>6.42</td>
<td>6.42</td>
<td>0.00</td>
<td>7.92 Sandout</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Main Frac</td>
<td>264.33</td>
<td>55+20P+60</td>
<td>7.61 to Slug</td>
<td>99.66</td>
<td>63.66</td>
<td>35.00</td>
<td>11.26 TSO-shape slight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mini Frac</td>
<td>187.01</td>
<td>60</td>
<td>two Slugs</td>
<td>4.61</td>
<td>4.61</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Main Frac</td>
<td>386.38</td>
<td>200</td>
<td>no</td>
<td>84.69</td>
<td>83.31</td>
<td>1.28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Data Frac 1</td>
<td>14.6</td>
<td>Breakdown</td>
<td></td>
<td></td>
<td>0.00</td>
<td>30.09.2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Data Frac 2</td>
<td>&amp;</td>
<td>Breakdown</td>
<td></td>
<td></td>
<td>0.00</td>
<td>01.10.2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Erosion Frac”</td>
<td>274.5</td>
<td>Gal-Slag+2 Sand Slugs</td>
<td>1.100</td>
<td></td>
<td>0.00</td>
<td>02.10.2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Mini Frac 1</td>
<td>96.6</td>
<td>26</td>
<td>1ppg Slug</td>
<td>0.60</td>
<td>0.60</td>
<td>0.00</td>
<td>03.10.2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Mini Frac 2</td>
<td>96.6</td>
<td>25</td>
<td>0.5-3 ppg Slug</td>
<td>1.04</td>
<td>0.90</td>
<td>0.14</td>
<td>03.10.2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5</td>
<td>Total</td>
<td>2617.3</td>
<td></td>
<td></td>
<td>1.100</td>
<td>1.64</td>
<td>1.50</td>
<td>0.137</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Proppants:** 407 tonnes  
**Clean Fluids:** 2 618 m³  
(during fracturing treatments)  
**Total Injection:** 3 172 m³
### LEER Z4: Fracture Treatments - Friction Results

<table>
<thead>
<tr>
<th>Frac</th>
<th>Treatment</th>
<th>Perforation Friction bar</th>
<th>Tortuosity Friction bar</th>
<th>total Friction bar</th>
<th>Ratio of Fracture on total Fric.</th>
<th>Ratio of Fracture on total Fric.</th>
<th>effective Perfo. PEG</th>
<th>effective Perfo. Halli.</th>
<th>effective Perfo. selected</th>
<th>Ratio eff. Perfo. selected</th>
<th>total Number of Perf.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SRDT</td>
<td>180</td>
<td>47</td>
<td>227</td>
<td>21%</td>
<td>79%</td>
<td>4</td>
<td>4</td>
<td>20%</td>
<td>20</td>
<td>20</td>
<td>pre Mini Frac</td>
</tr>
<tr>
<td>2</td>
<td>SRDT 1</td>
<td>95</td>
<td>93</td>
<td>188</td>
<td>49%</td>
<td>51%</td>
<td>3</td>
<td>4</td>
<td>20%</td>
<td>20</td>
<td>20</td>
<td>post Mini Frac</td>
</tr>
<tr>
<td>2</td>
<td>SRDT 2</td>
<td>51</td>
<td>81</td>
<td>132</td>
<td>61%</td>
<td>39%</td>
<td>4</td>
<td>4</td>
<td>20%</td>
<td>20</td>
<td>20</td>
<td>post Mini Frac</td>
</tr>
<tr>
<td>3</td>
<td>SRDT 1</td>
<td>227</td>
<td>18</td>
<td>245</td>
<td>7%</td>
<td>93%</td>
<td>2</td>
<td>3.7</td>
<td>15%</td>
<td>20</td>
<td>20</td>
<td>pre Mini Frac</td>
</tr>
<tr>
<td>3</td>
<td>SRDT 2</td>
<td>60</td>
<td>63</td>
<td>129</td>
<td>53%</td>
<td>47%</td>
<td>3</td>
<td>5.3</td>
<td>20%</td>
<td>20</td>
<td>20</td>
<td>post Mini Frac</td>
</tr>
<tr>
<td>4</td>
<td>SRDT 1</td>
<td>108</td>
<td>25</td>
<td>133</td>
<td>19%</td>
<td>81%</td>
<td>2</td>
<td>4.5</td>
<td>20%</td>
<td>20</td>
<td>20</td>
<td>pre Mini Frac</td>
</tr>
<tr>
<td>4</td>
<td>SRDT 2</td>
<td>81</td>
<td>41</td>
<td>122</td>
<td>34%</td>
<td>66%</td>
<td>3</td>
<td>4.5</td>
<td>20%</td>
<td>20</td>
<td>20</td>
<td>post Mini Frac</td>
</tr>
<tr>
<td>5</td>
<td>SRDT</td>
<td>144</td>
<td>45</td>
<td>189</td>
<td>24%</td>
<td>76%</td>
<td>7</td>
<td>12</td>
<td>30%</td>
<td>30</td>
<td>30</td>
<td>pre Mini Frac</td>
</tr>
</tbody>
</table>

#### Mean Pre
- Perforation Friction bar: 151 m
- Tortuosity Friction bar: 46 m
- Total Friction bar: 196 m
- Ratio of Fracture on total Fric.: 23%
- Ratio of Fracture on total Fric.: 77%
- effective Perfo. PEG: 4
- effective Perfo. Halli.: 4
- Remarks: 20 pre Mini Frac

#### Mean Post
- Perforation Friction bar: 64 m
- Tortuosity Friction bar: 64 m
- Total Friction bar: 128 m
- Ratio of Fracture on total Fric.: 50%
- Ratio of Fracture on total Fric.: 50%
- effective Perfo. PEG: 4
- effective Perfo. Halli.: 3
- Remarks: 20 pre Mini Frac

### LEER Z4: Fracture Treatments - Fracture Results

#### LEER Z4 - Fracture Geometric Results

<table>
<thead>
<tr>
<th>Frac</th>
<th>Fracture Half Length xf (m)</th>
<th>Fracture Height xh (m)</th>
<th>Fracture Conductivity wf&quot;kf with 50% Damage md.m</th>
<th>Final Proppant Concentration at Perforation (g/l)</th>
<th>Final Proppant Concentration at Perforation (ppg)</th>
<th>CarboProp 20/40 Proppants in Formation (tons)</th>
<th>Fracture Width at Perforation (mm)</th>
<th>Average Fracture Width (mm)</th>
<th>Reservoir Pressure @4420 m TVDss BHSIP (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>76</td>
<td>77</td>
<td>550</td>
<td>890</td>
<td>7.4</td>
<td>69.4</td>
<td>3</td>
<td>2</td>
<td>531</td>
</tr>
<tr>
<td>2</td>
<td>97</td>
<td>62</td>
<td>1000</td>
<td>1300</td>
<td>10.8</td>
<td>88.1</td>
<td>7</td>
<td>3</td>
<td>487</td>
</tr>
<tr>
<td>3</td>
<td>105</td>
<td>66</td>
<td>1250</td>
<td>1440</td>
<td>12.0</td>
<td>113.2</td>
<td>9</td>
<td>4</td>
<td>614</td>
</tr>
<tr>
<td>4</td>
<td>69</td>
<td>93</td>
<td>1500</td>
<td>1230</td>
<td>10.3</td>
<td>135.2</td>
<td>10</td>
<td>5</td>
<td>606</td>
</tr>
</tbody>
</table>

LEER Z4: Frac 1-4 (5):
Fracture Treatments: Friction Results and Fracture Dimensions
LEER Z4: Well Cleanout/Tracer Analysis
Result of Fluid Flowback

- Frac 3: Continuous increase in total tracer concentrations suggests progressive flowback/cleanup and diminution of untraced fluids.

- Frac 4: Flowback/cleanup by Frac 1 & 2 intervals virtually nonexistent.

- Frac 1+2:
The Leer Z4 was designed with a “mono bore”-Cr13-95-completion, which was used during the well simulation and is used as a production string.

Fracture initiation was generated in high stress zones, while the fracture propagates into low stress zones, which were generated by lower reservoir pressures.
Problem: Fracture stabilization, fracture width and fracture propagation: Risk of pre-mature screenout.

Each fracture has been marked by individual tracers.
During well cleanout and later production: Quantitative observation on fracture contribution.

On the fly-coating with special resin (Expedite XP) prevents backflow of proppants.

The scheduled temporary shut-off of stimulated fractures with composite bridge plugs was not possible. As an “alternative” sand plugs were used to shut-off the prior stimulated perforation.

Problems:

- Well head pressure must be kept in the range of 260 – 300 bar to perform sand cleanout with coiled tubing and to ensure stability of the temporary sand plug.
  Disadvantage applying high back pressure: critical low fluid velocity (limited hydraulic power) and enhanced erosion on the used 2” coiled tubing.

- In general: Very limited access to the reservoir. Effective number of perforation holes (3-4).

- Formation breakdown with fracture initiation: Risk of sand blocks due to residual proppants from prior treatments.
Despite tectonic and facies insecurities:
An optimized access of the upper section of the Wustrow-Sandstone was reached.

Main contribution of successful geo-steering was the application of LWD-Tools.

During the construction of the well site a gas connection to the public gas network was installed to ensure energy supply to heat-up the fracture fluids.

Application of transportable gas-heaters to warm-up the fracture fluids:
A quick and flexible heating system was created.

Concept: Fracture treatment with “mono-bore” completed well.
No workover after stimulation is needed. The aim is to use the completion during the first production years to reach an economic project.

Sirocco gels and „Expedite (XP)“ applied as „on the fly - coating“ was found to be useful.

The concept of the fracture treatment was adopted to the local circumstances and improved:
General strategy: Data Frac 1, Mini Frac, Data Frac 2 und Main Frac.

The well azimuth (about ENE) reached at least a relative low tortuosity friction.

Application of individual markers (tracers) were quite successful.

On the well location the fracture stimulation team was present during all stages of the treatment.
Limited access to the reservoir through generally 3-4 big hole perforations with relatively high initial perforation friction.

Problem to maintain fracture width stability during the fracture initiation, especially by fracturing a high stress zone while the fracture propagation will allocate low stress zones.

The Mini Frac gel volume must be enhanced significantly to reach about 2/3 of the main fracture height to ensure more “Main Frac”-treatment-security. This was caused by vertical reservoir pressure changes in the sandstones and thus unexpected vertical stress differences.

Due to the dogleg severity and a completion with relatively thick tubing wall the planned composite bridge plugs could not be set.

By applying the “alternative” sand plugs disadvantages occurred:

High back-pressure, instable plug settings, additional time loss, insufficient well sandout treatments with coiled tubing (limited circulation rates), higher coiled tubing erosion, formation breakdown with linear gel due to residual sands, risk of sand bridges in the next treatment.

→ For follow-up “tight gas” projects: Changes in the well path design and the well completion.
We like to thank our Leer consortial partner Wintershall AG for the possibility to present this “tight gas” - contribution.
“Tight Gas” Challenges – Key Issues:
- Knowledge of reservoir characteristics
- Horizontal wells in HTHP environment
- Stimulation design technologies