# Bakken Horizontal Best Practices Review

**September 2005**

Landmark
A Halliburton Company

# SPE 90697

## Improved Horizontal Well Stimulations in the Bakken Formation, Williston Basin Montana


| | |
|---|---|
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***SPE Presentation***

***October 2004***

***Denver, Colorado***

# Outline

- Area Overview and Geology
- Reservoir Modeling & Well Performance
- Evolution of Well Construction
- Evolution of Completion & Frac Design

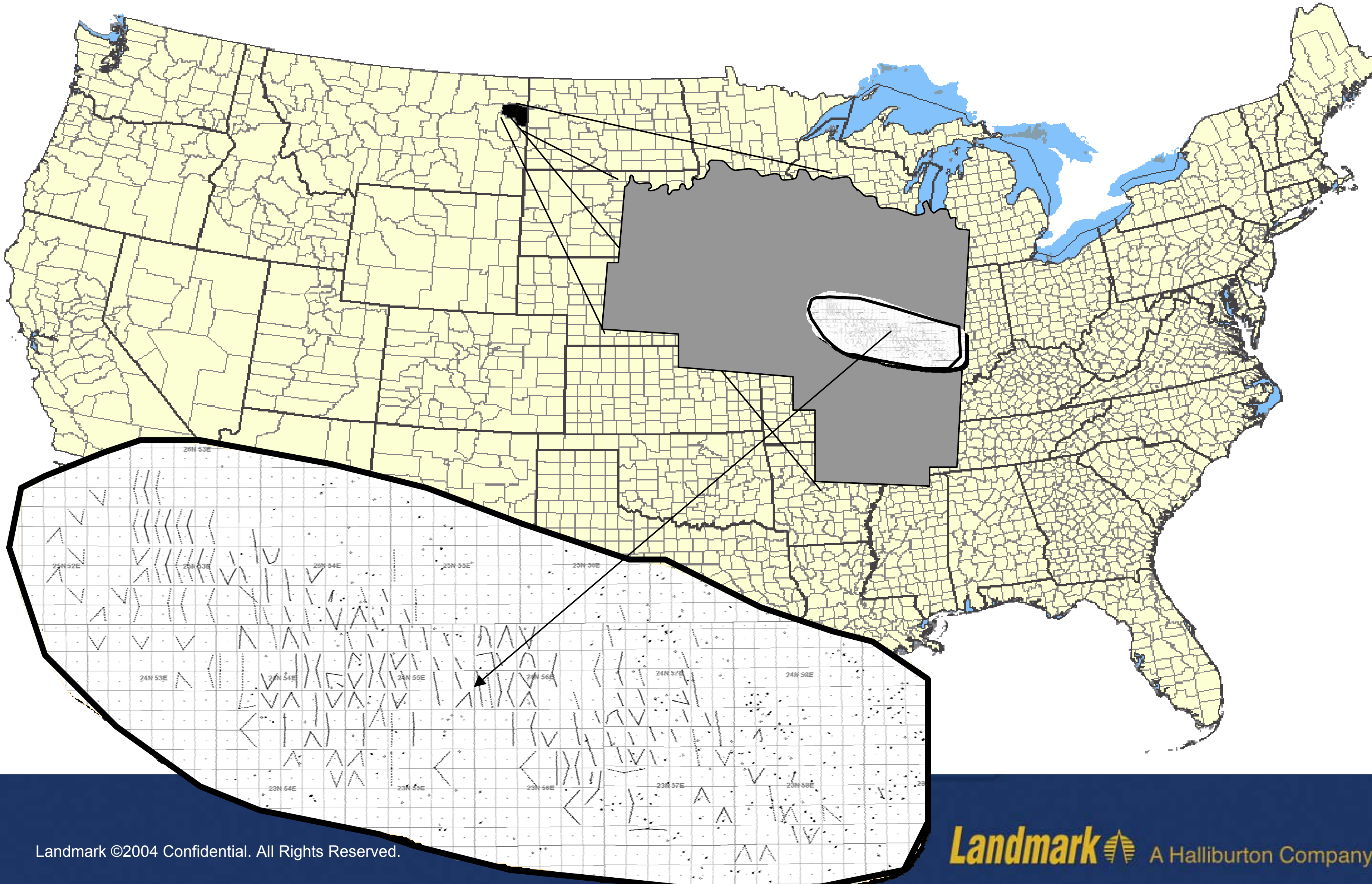
# Early Challenges:

- Can horizontal wells provide economic uplift for development?
- Is stimulation required for success?
- Can laterals be effectively stimulated?
- What is effective drainage area for low K reservoir?

# Short Answers:

- Yes
- Yes
- Yes
- More than you would think

# Sleeping Giant Bakken Play



# Area Overview & Geology

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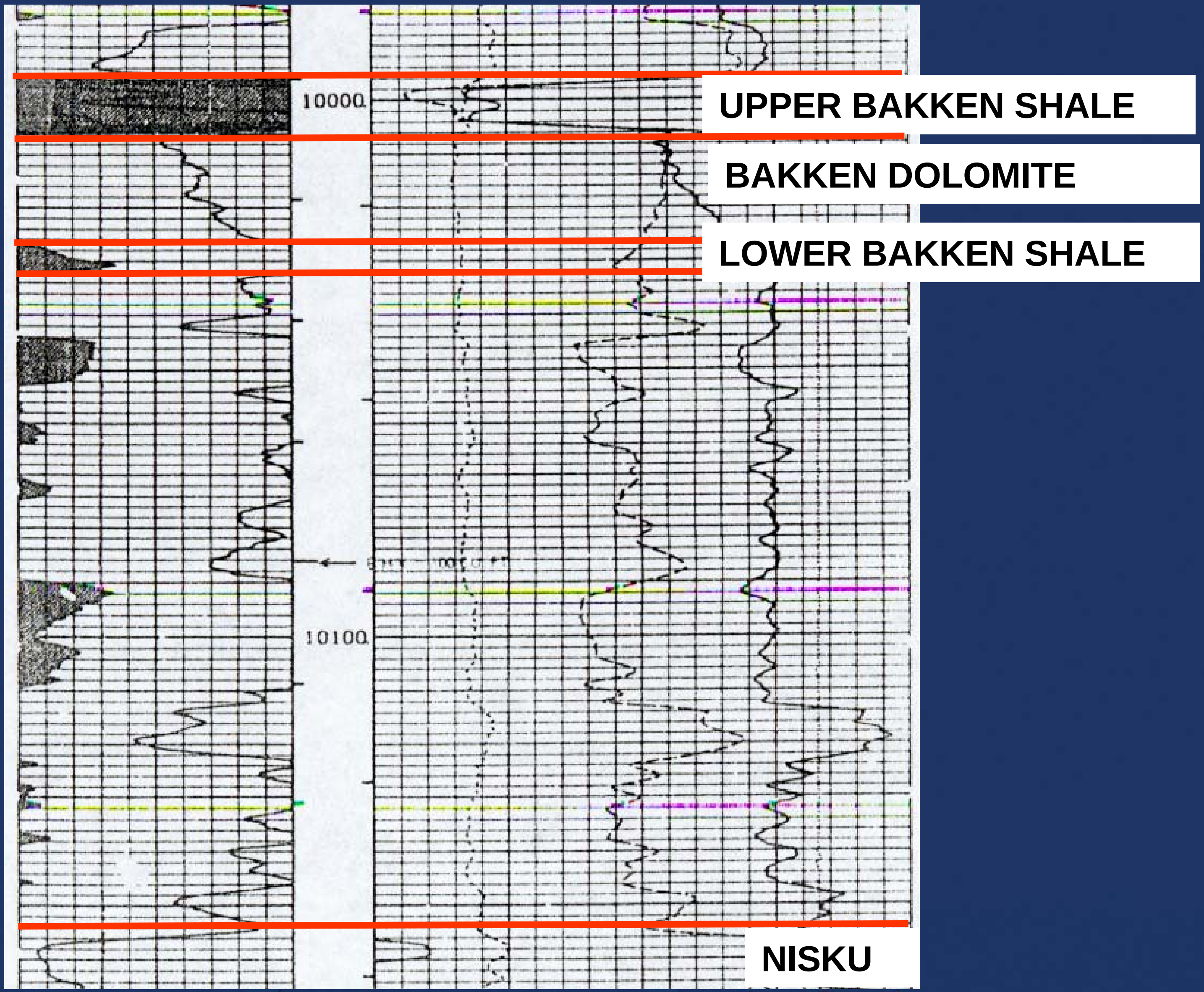
# Middle Bakken Geologic Summary

- Reservoir rock is a dolomite, slightly shaly, minor calcite and quartz grains
- Consistent lateral extent and uniform vertical stratigraphy
- Lateral gradation to siltstones and sandstones
- Sourced by organic-rich shales above and below
- Stratigraphically trapped by porosity pinchout, primarily to NE and SW
- Dominantly matrix porosity system with minor fracturing

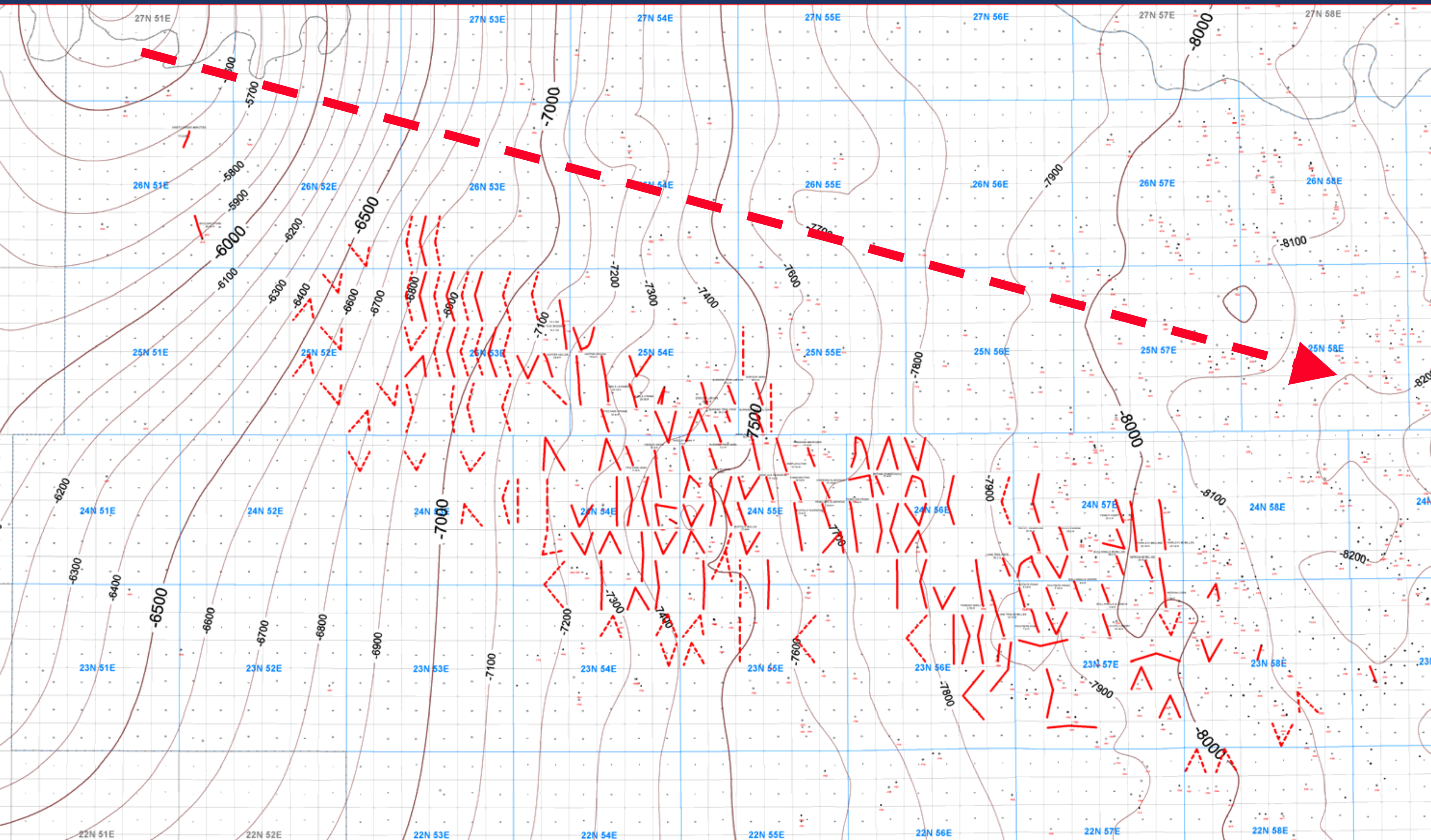
# Bakken Reservoir Properties

- Net Thickness: 6 – 15 ft
- Porosity:  8 – 12%
- Permeability: 0.05 - 0.5 md
- $K_v/K_h = 0.1$
- Water Sat.: 15 – 25%
- Oil Gravity:  42 API
- GOR: 500 scf/stb

# Type Log - Bakken



# Structure Map – Top of Bakken Shale



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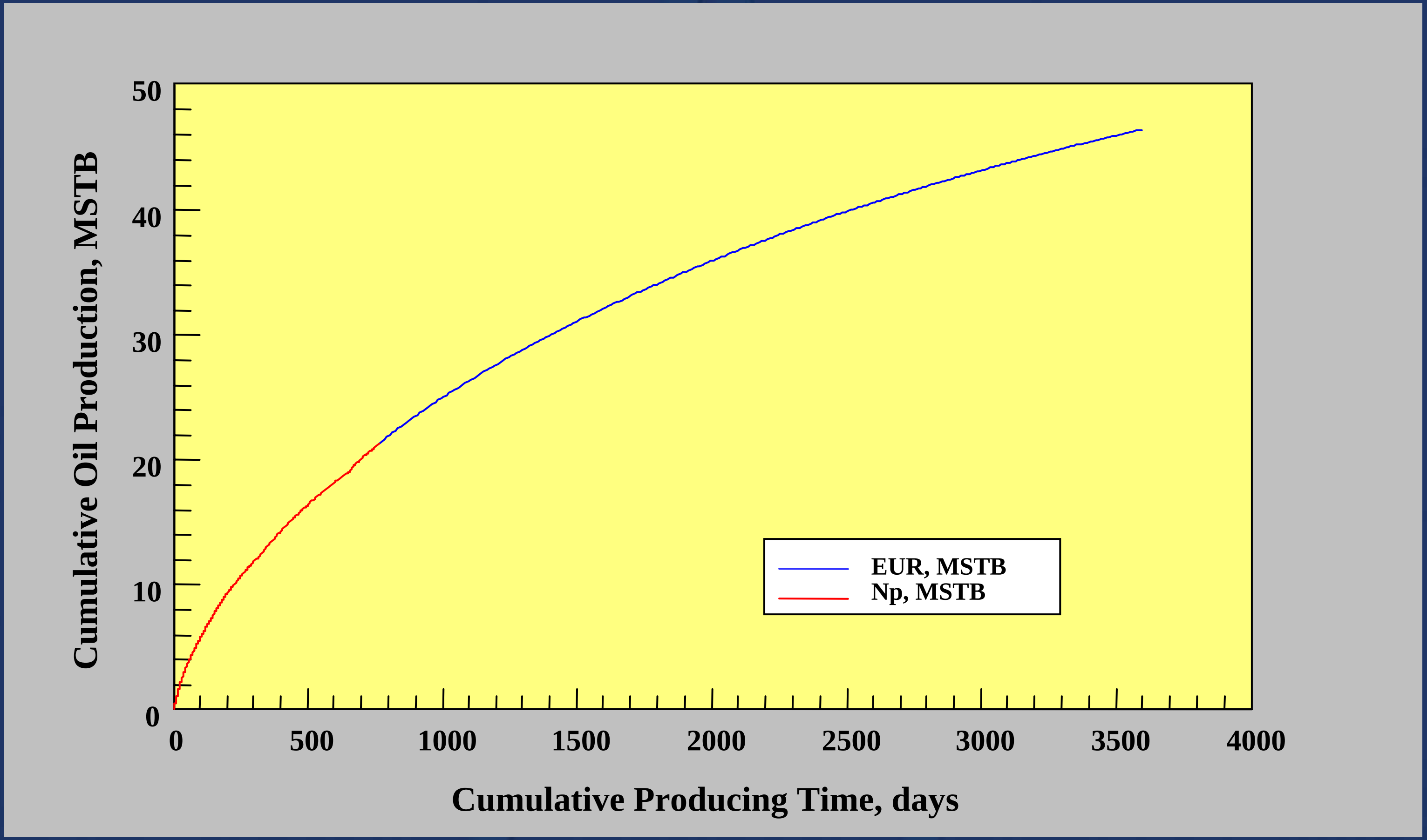
# Modeling Results

# Initial Reservoir Modeling

- Objective: Define potential benefit of horizontal completion
- History match performance of vertical Bakken producers – using reservoir parameters from logs, cores and well tests
- Use history matched reservoir model for mechanistic study to determine:
  - Productivity uplift from horizontal completions
  - Optimal orientation of laterals
  - Benefit of stimulation in lateral section
  - Estimated effective drainage area

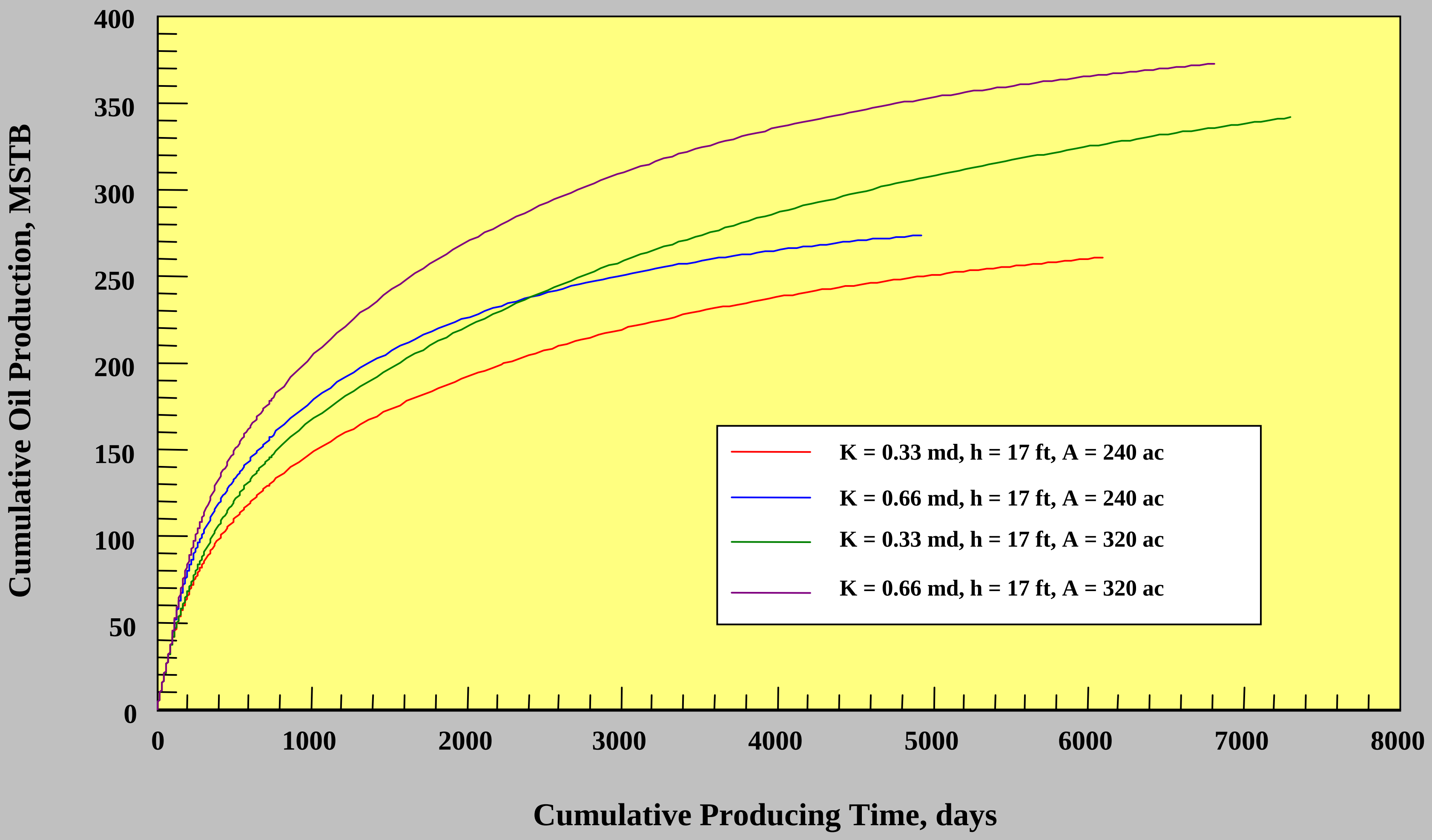
# Vertical Well
## Estimated Ultimate Recovery



# Horizontal Well Simulation
## Input Parameters

- 3-4 independent fractures totaling 2,000 ft.
- 3,000 ft horizontal lateral.
- Drainage area
  - 160, 240, & 320 acres
- Permeability
  - 0.165 md
  - 0.330 md
  - 0.660 md
- Lateral Orientation – Longitudinal vs Transverse fracture

# Horizontal Well Simulation
## Estimated Ultimate Recovery
### (240 & 320 Acres)

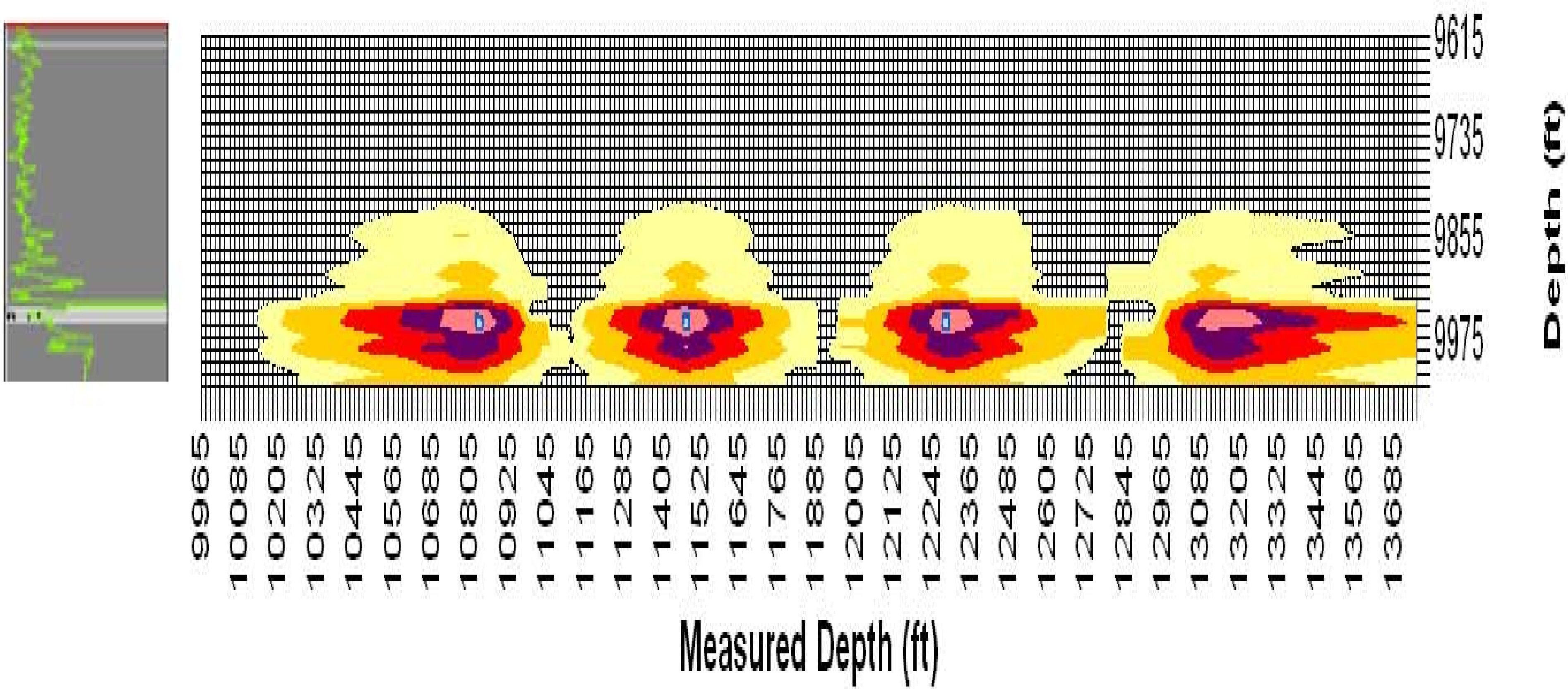


# Frac Design Simulation

- **Study fracture growth character** –
  - estimate proppant placement in zone
  - height growth
  - perforating effects

- **Study frac job design** –
  - determine effect of proppant type & concentration
  - determine effect of job parameters

# Fracture Simulation



# Key Modeling Conclusions

- <u>**Hydraulic fracturing**</u> **- needed due to low perm, low $K_v/K_h$, limited natural fracturing**
- <u>**Fracture Orientation**</u> **– longitudinal vs transverse fracture growth**
  - Simulation shows negligible reserve differences
  - Cost effective fracture placement more likely with single stage longitudinal frac

# Key Modeling Conclusions

- <u>Maximize stimulated length</u> – needed to improve productivity and drainage effectiveness

- <u>Establish Uniform Spacing</u> – create well design that allows for consistent downspacing if justified

# Well Construction & Completion

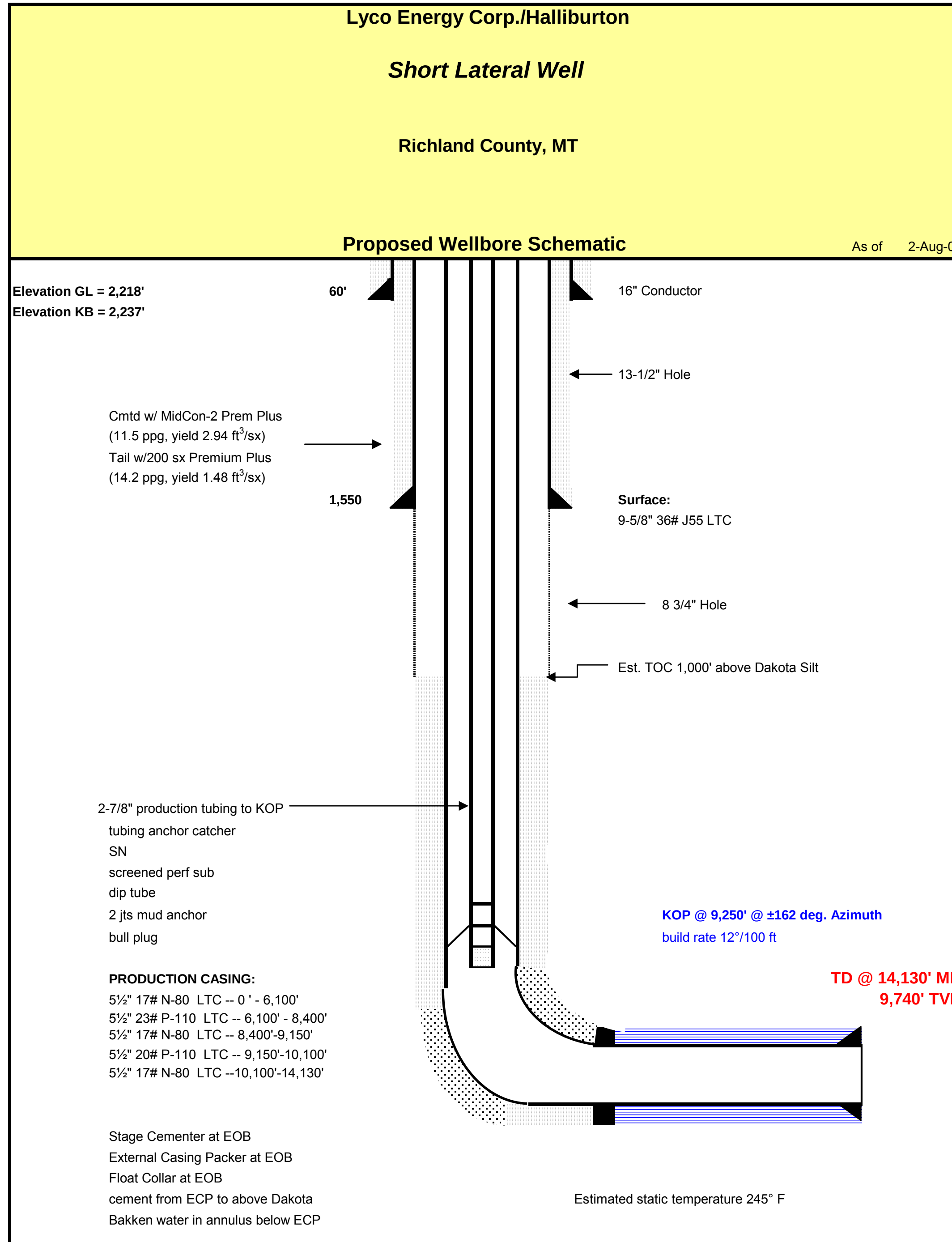
# Current Best Practices Basic Well Design

- Drill Vertical & Curve, Land In-Zone w/ No Pilot Hole.
- Drill Lateral Along Maximum Principal Stress Azimuth to Facilitate Longitudinal Hydraulic Fracture.
- Drill Lateral to Maximum Length Allowable Per Spacing.
- Run Uncemented Pre-Perforated Liner to Toe to Permit Clean-out & Other Re-Entry.
- Fracture Stimulate w/ Low Loading Polymer and Large Volume of Sand Proppant.  Use Diversion Techniques.

# Short Lateral

**Short laterals are 4,000' in length**

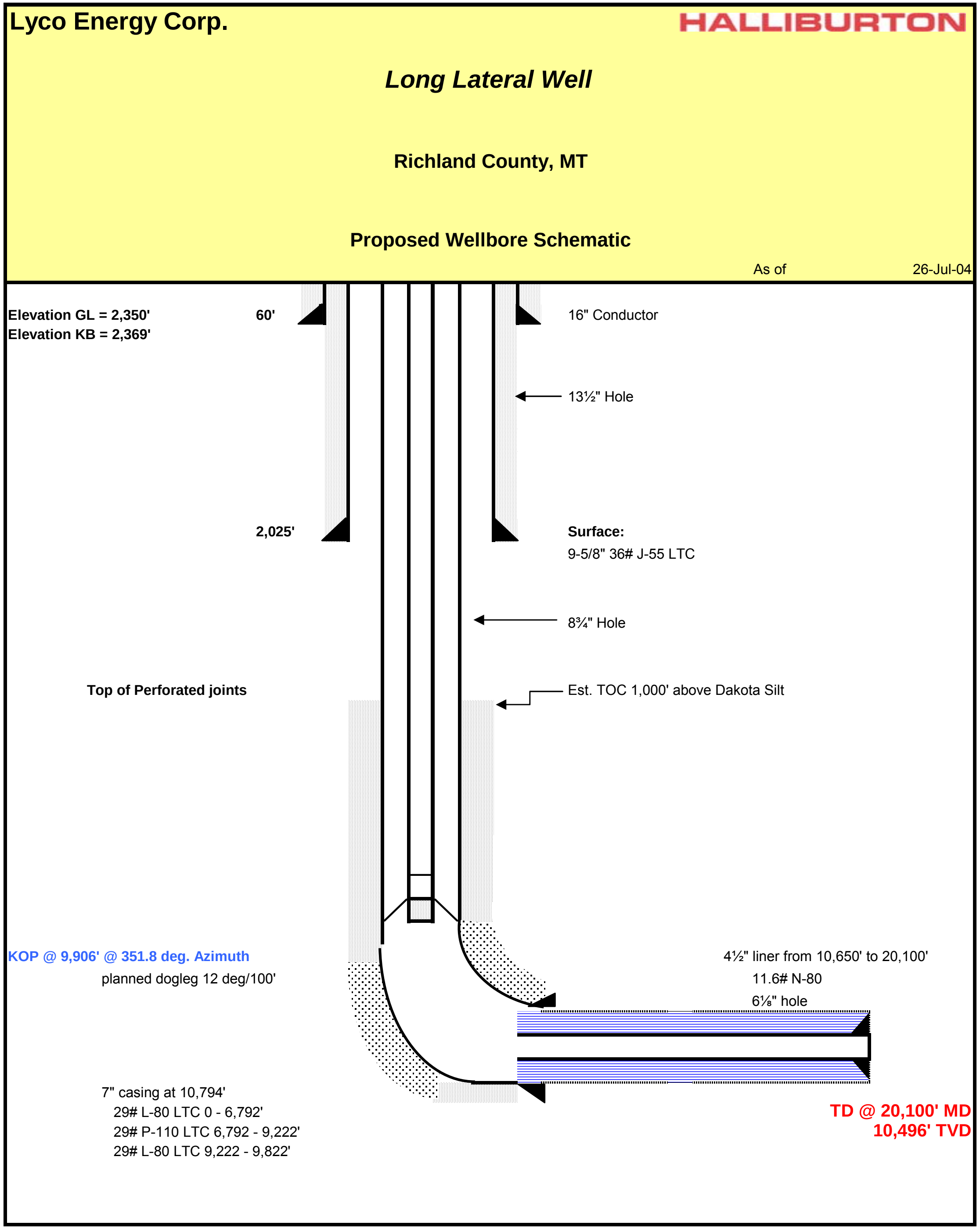
**Single 640 acre Section Spacing**



# Long Lateral

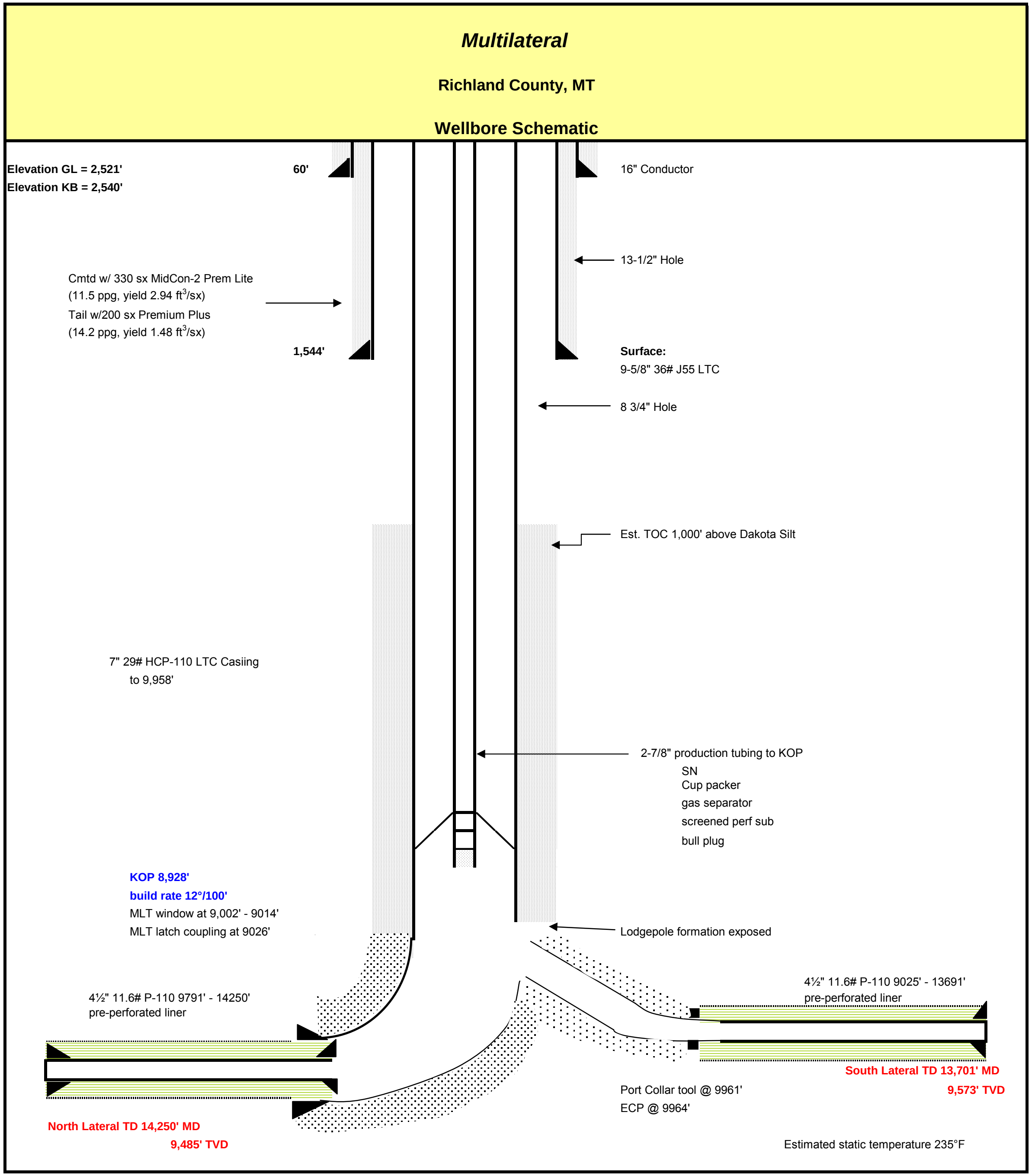
**Lateral length of +/- 9000'**

**Double section - 1280 acre spacing**



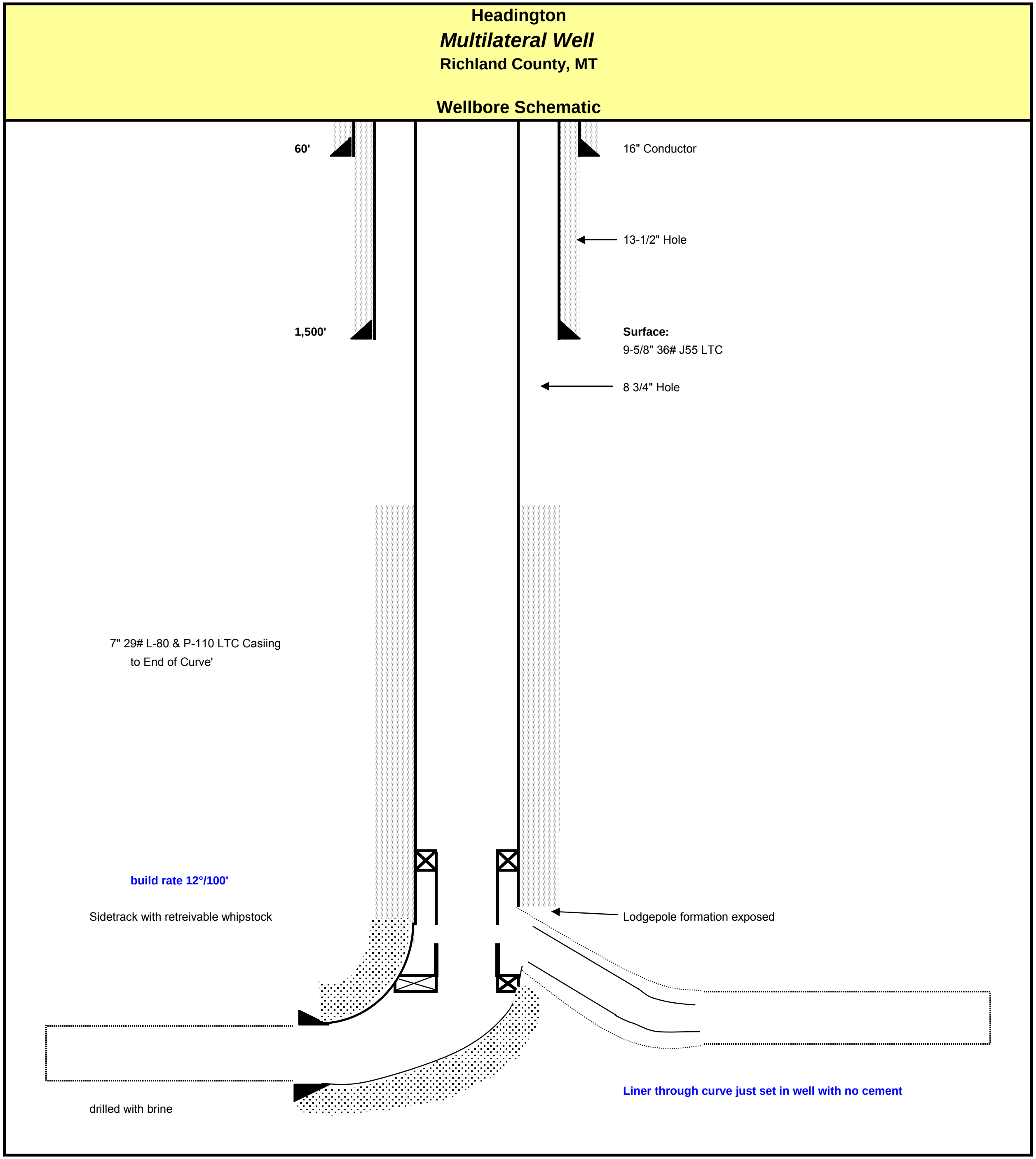
# Multi-lateral Uncemented Liner

## Single or Double Section Development

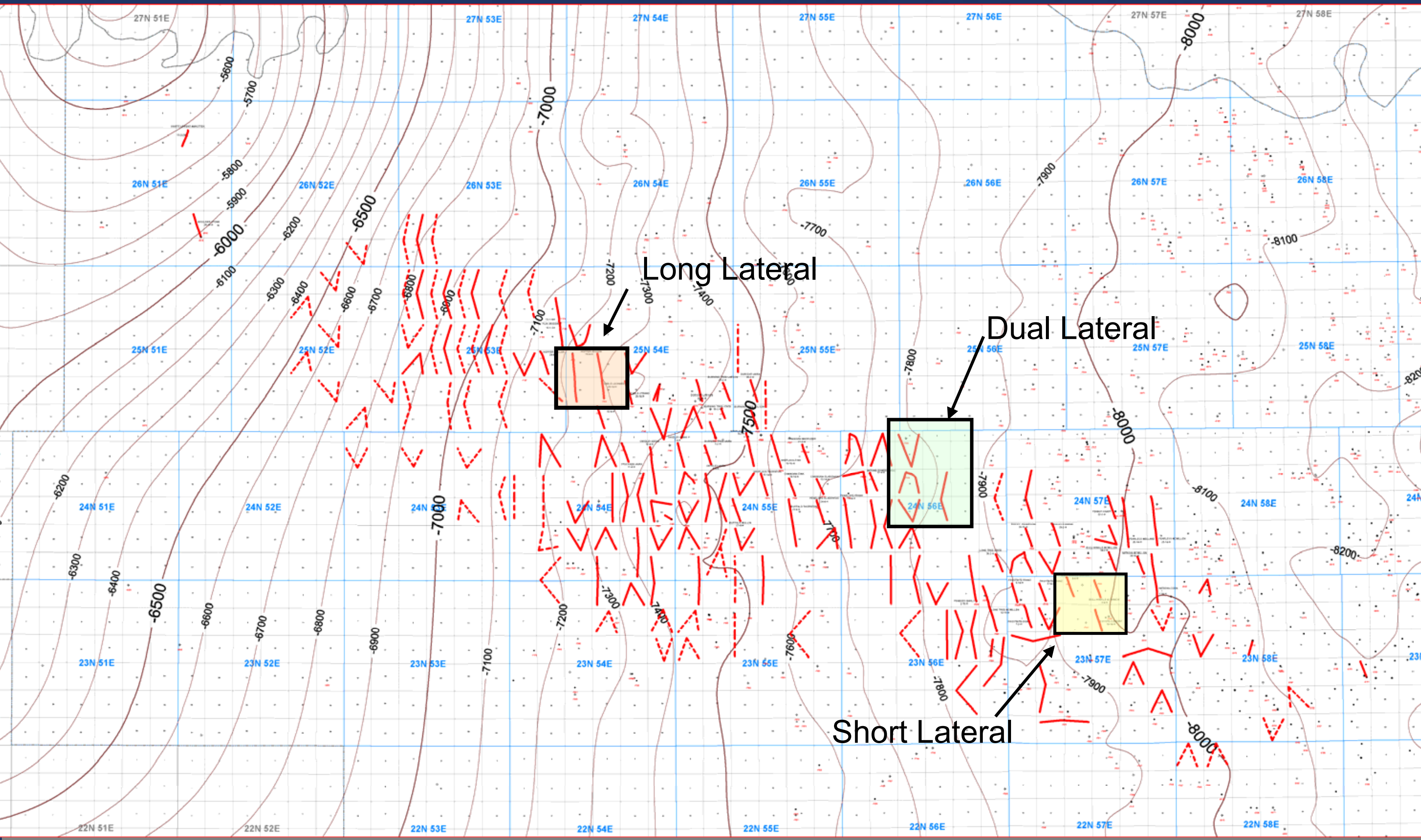


# Multi-lateral Open Hole

## Single or Double Section Development



# Well Types



Long Lateral
Dual Lateral
Short Lateral
27N 51E
27N 53E
27N 54E
27N 55E
27N 56E
27N 57E
27N 58E
26N 51E
26N 52E
26N 53E
26N 54E
26N 55E
26N 56E
26N 57E
26N 58E
25N 51E
25N 52E
25N 53E
25N 54E
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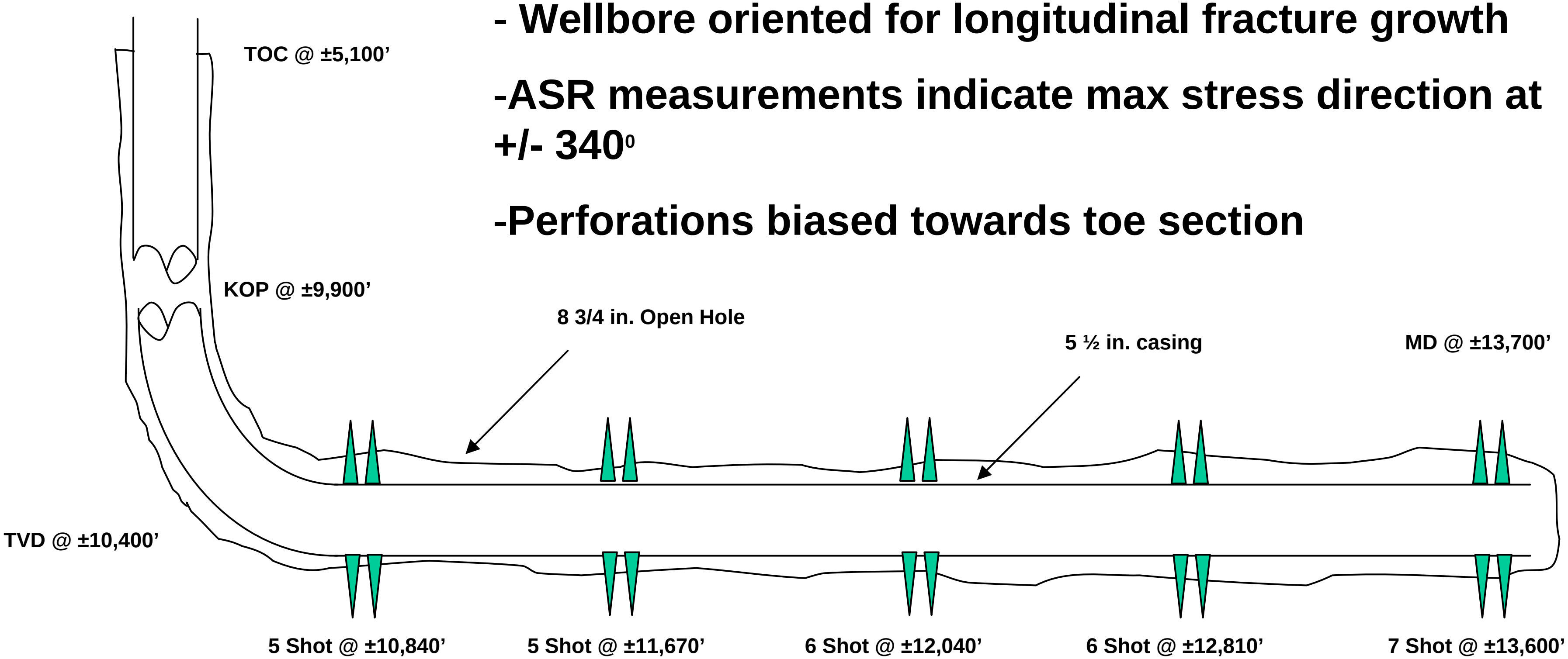
-7600
-7700
-7800
-7900
-8000
-8100
-8200

# Early Completion Design

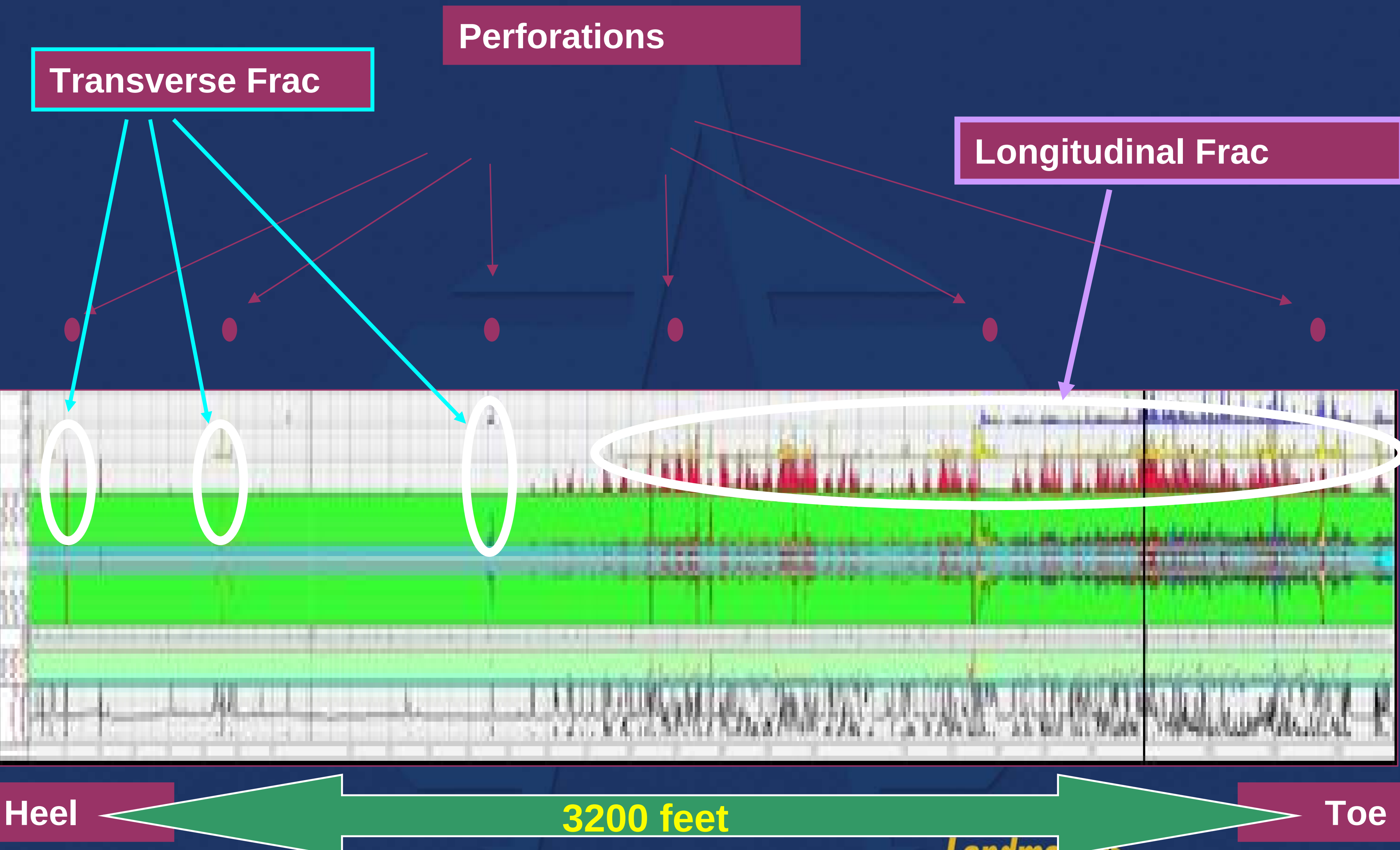
- Wellbore oriented for longitudinal fracture growth

-ASR measurements indicate max stress direction at +/- 340$^0$

-Perforations biased towards toe section



# Early Completion – Cemented Liner



# Why didn't the heel treat?

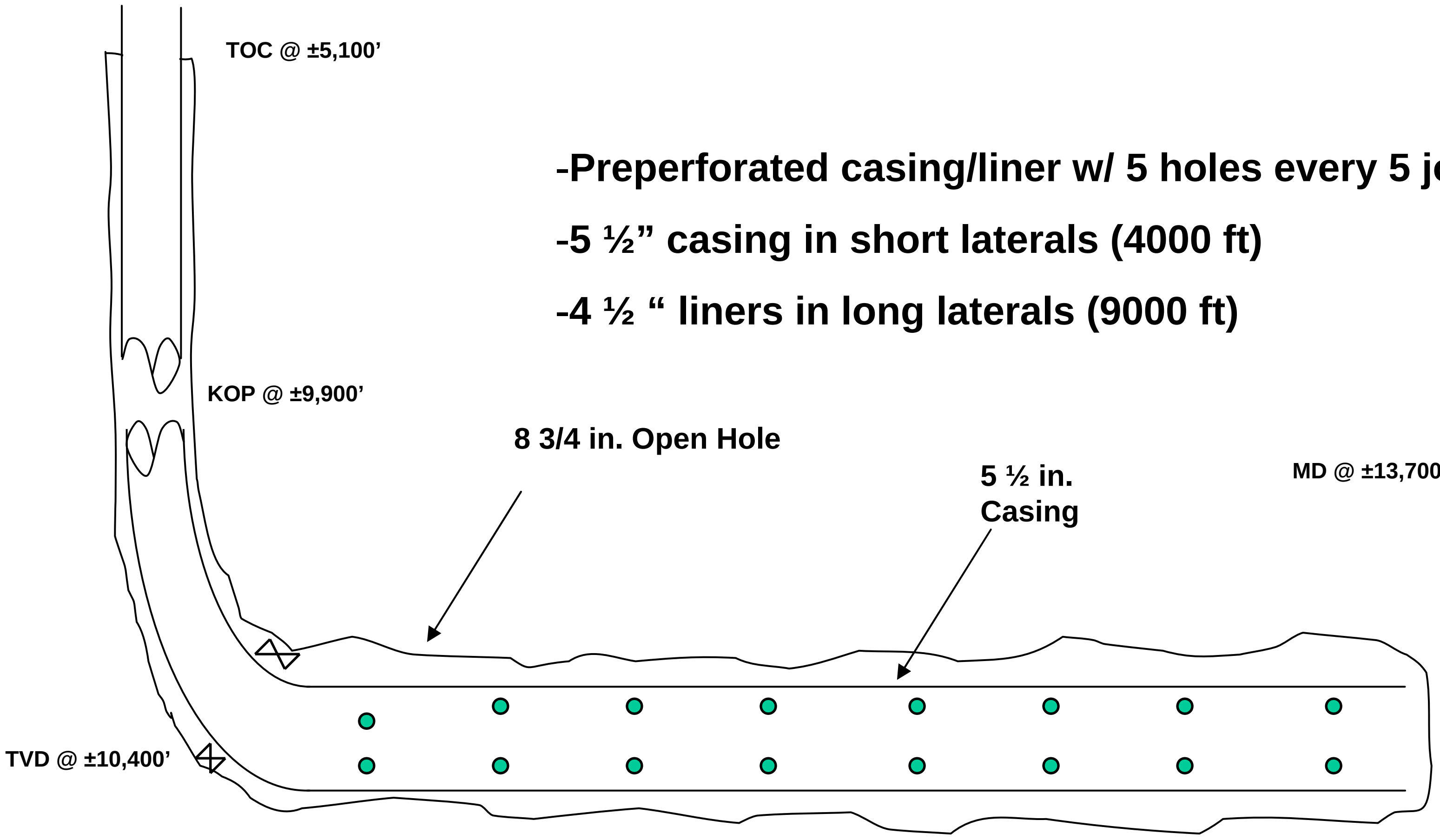
- **Drilling damage in the heel section from fines and extended exposure**
  - **Or**
- **Combination of damage in heel and lower pore pressure in toe cause toe to preferentially treat**

# Why an Uncemented Liner?

- **Problems with open hole fracs**
  - **Frac the heel only in open hole fracs**
  - **By using perforated casing able to divert the frac and treat the entire wellbore**
  - **SpectraScan tracer logs indicate improvement with this method**

- **Ability to easily re-enter wells**
  - **Cleanouts –**
    - **Medium lateral production increased from 175 bopd before cleanout to 691 after**
  - **Re-frac – ability to retreat poorly treated zones**
    - **Initial refrac treatment increased from 30 bopd before refrac to 190 after**

# Noncemented Liner Completion




-Preperforated casing/liner w/ 5 holes every 5 joints

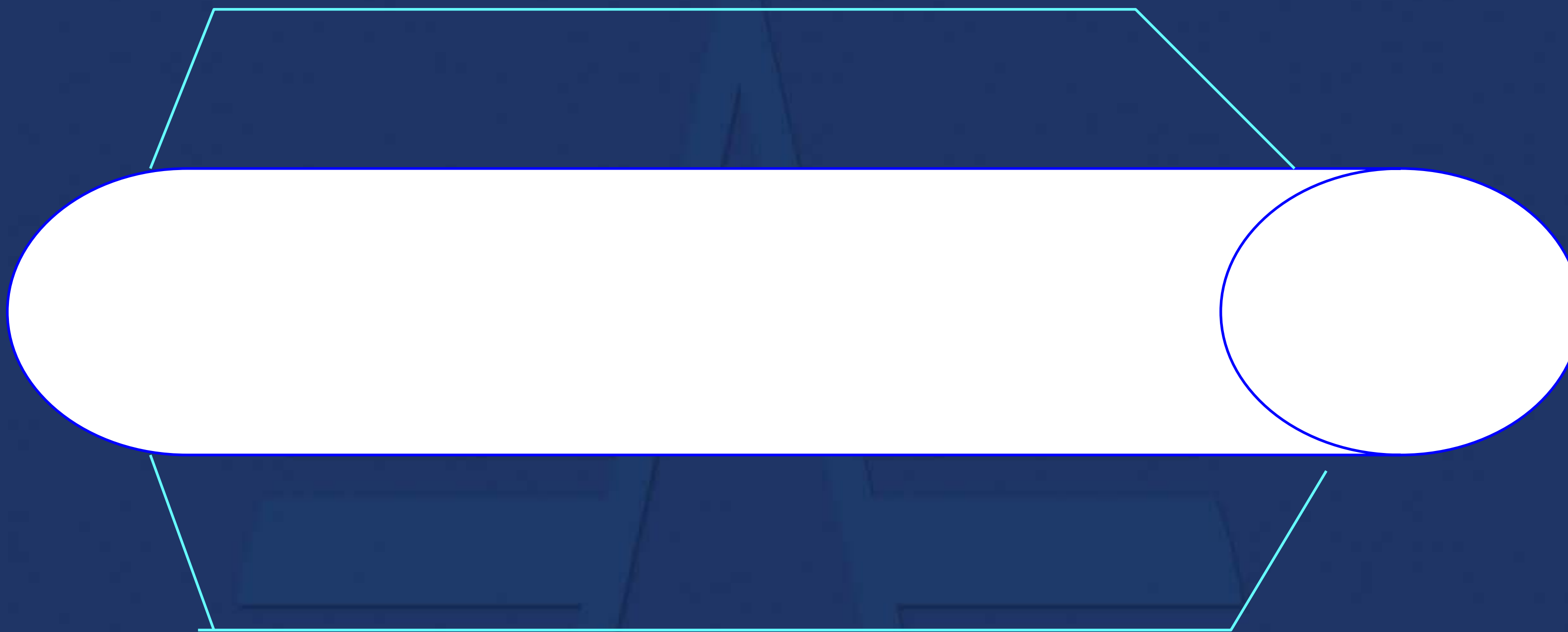
-5 ½" casing in short laterals (4000 ft)

-4 ½ " liners in long laterals (9000 ft)

# Evolution of Fracture Treatments

- Fluids Tried
  - Borate, Gelled Oil, CMHPG
- Proppants Tried
  - AcFrac Black (resin coated sand)
  - VersaProp (ceramic)
  - Sand
- Multistage jobs with ball sealers and high ppg sand slugs

# Why Sand at 10,000’ TVD?



Frac is longitudinal

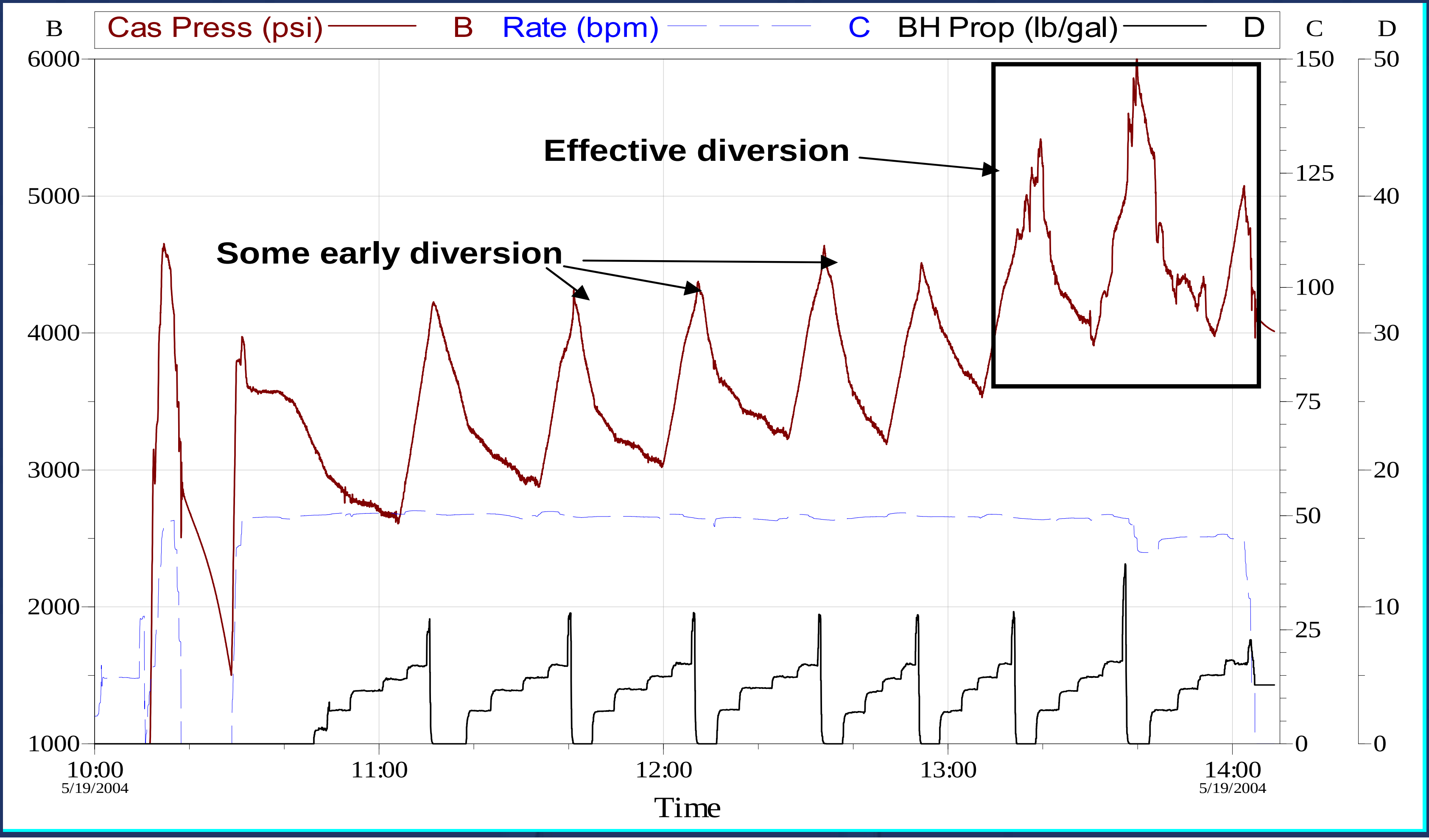
Only ~20’ high

Fluid flow path through sand is short

Increased perf spacing

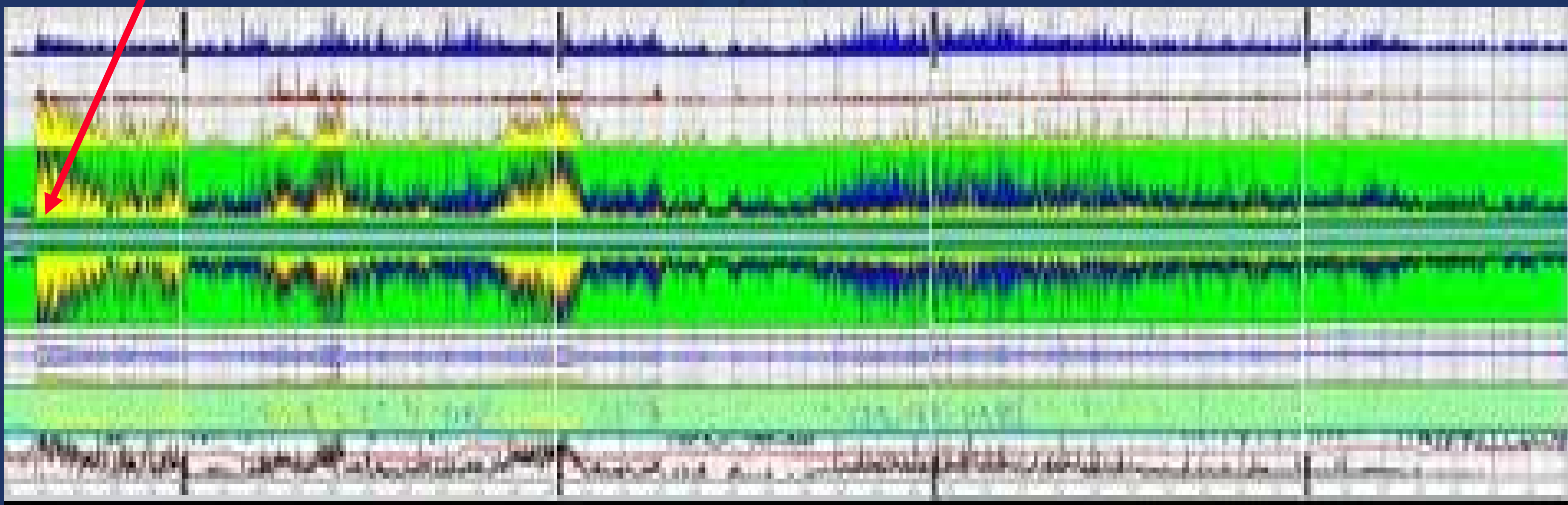
StimLab Predict-K predicts very little difference in production with different proppants.

# Multi-Stage Frac Design



# Tracer Log -Noncemented, Preperforated Liner

Start of noncemented liner



Heel 4000 feet Toe

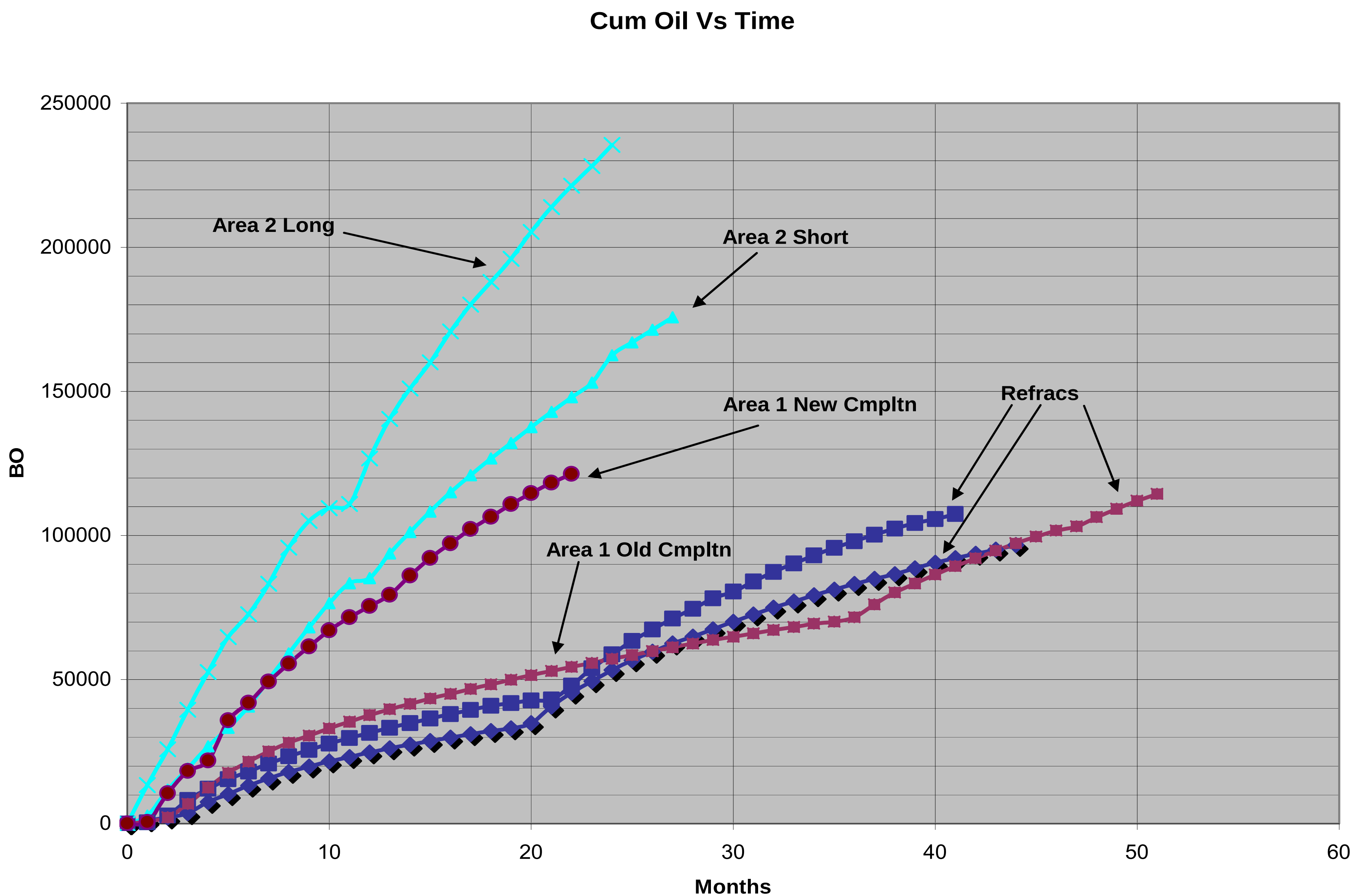
# Normalized Production Results

| | Average of MaxMo/1000’ | Average of 6MoProd/1000’ | Units |
|---|---|---|---|
| Current Comp | 2,015 | 10,985 | Bbl |
| Early Comp | 1,818 | 8,517 | Bbl |
| Operator A | 1,721 | 5,848 | Bbl |
| Operator B | 1,590 | --- | Bbl |
| Operator C | 1,396 | 5,730 | Bbl |
| Operator D | 1,157 | 4,993 | Bbl |

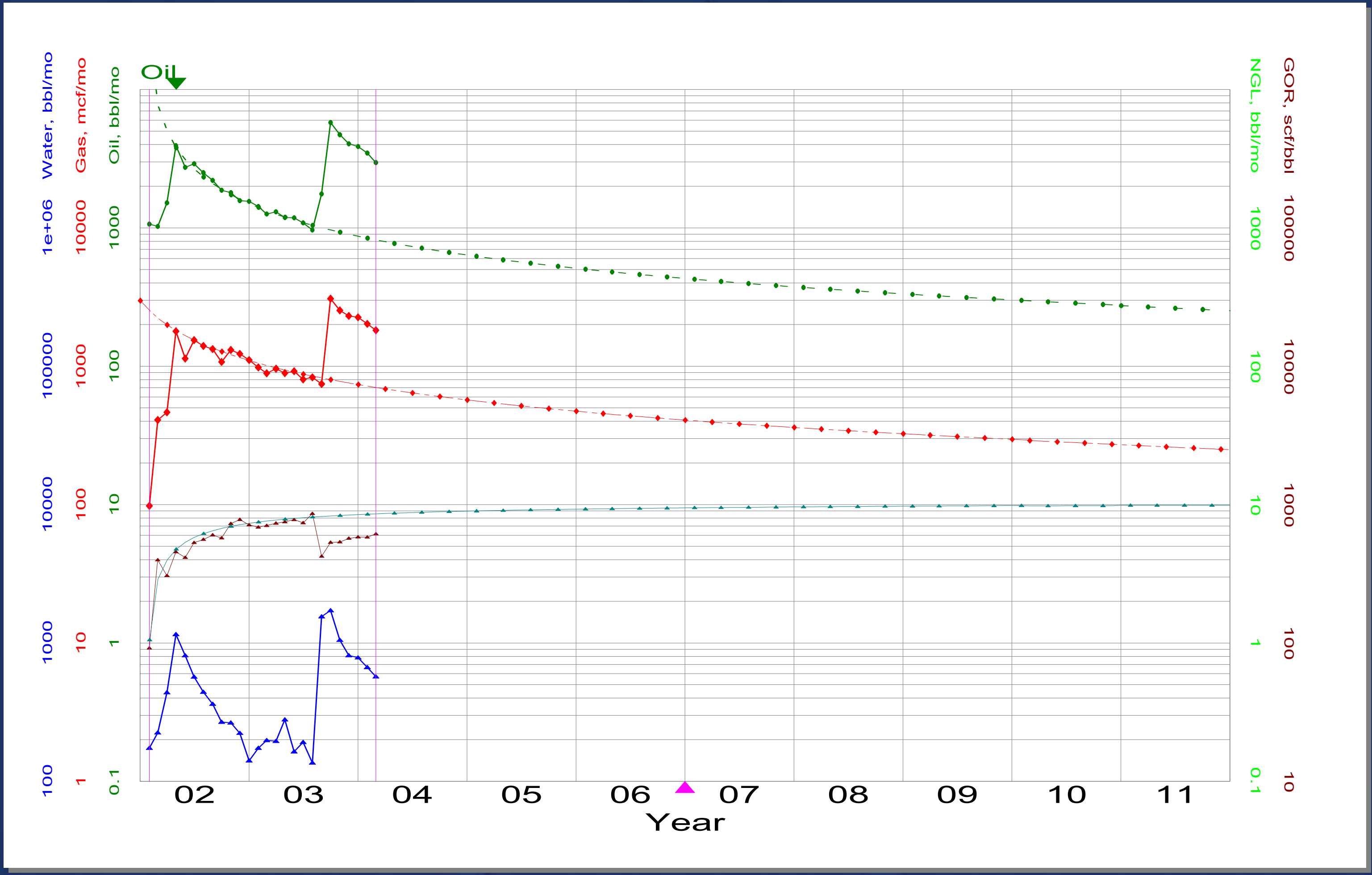
# Normalized Production Results – Updated – April, 2005

| | Average of 6MoCum/1000' | Average of 12MoCum/1000' | Units |
|---|---|---|---|
| Current Comp | 9,897 | 17,358 | Bbl |
| Early Comp | 8,517 | 14,323 | Bbl |
| Operator A | 6,881 | 11,442 | Bbl |
| Operator B | 7,351 | 12,806 | Bbl |
| Operator C | 5,627 | 9,457 | Bbl |
| Operator D | 5,099 | 8,997 | Bbl |

# Well Performance Comparison



# Cemented Short Lateral: 3034’ Re-Frac of Original Well w/ Current Approach



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# Further Refinements

- Stimulation Design
  - Increase number of stages & diversion
  - Continue efforts to facilitate frac cleanup
- North Dakota Development
  - Lodgepole Fm integrity favors isolation of curve section
  - Apparent lower reservoir quality places increased emphasis on completion efficiency

# Conclusions

- Maximum stimulated lateral length is primary factor in well productivity
- Positive diversion techniques improve fracture coverage
- Noncemented, perforated liners allow effective diversion and treatment of long lateral sections
- Both longitudinal and transverse fractures are created along the lateral length
- Tendency of the lateral to frac back from toe to heel has been consistently observed
- Refracturing of early wells has improved lateral coverage, well production and total recovery

# Questions?

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