Improving Horizontal Well Placement and Completion Effectiveness in Deltaic Tight Sands - A Case Study in Anadarko Basin*

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Abstract

The Upper Pennsylvanian Cleveland tight sands in Anadarko Basin consist of very fine-grained and well-sorted sands that are interbedded with thin mudstones and siltstones. Reservoir sands are interpreted as tidally reworked fluvial deltaic systems, where clean sand bodies are mixed in with sand-shale lamination sequences, which present a high degree of ambiguity when geosteering horizontal wells. In the past year, we have successfully drilled and completed more than two dozen horizontal wells in low porosity (3-15 p.u) and low permeability (4-400 uD) reservoirs. Subtle stratigraphic variations in these rocks have a profound impact on well productivity and ease of completion. Though the net sand package is 80-120 feet thick, the primary hydrocarbon producing rock type is only 8-30 feet thick. Low commodity prices demand low well costs and in general a basic MWD gamma ray (GR) tool is employed against offset vertical well coverage of variable quality. The task of landing and chasing ~10 foot thick sands along a 4000 foot lateral is daunting. Squeezing/stretching of MWD GR's to match the log character often results in a non-unique interpretation. We have observed inconsistencies in tool calibration among several MWD tools; an increasing separation between the true and MWD GR values was noticed with increase in shaliness.

A calibrated GR log is essential in steering long laterals in these complex reservoirs. For this purpose, we acquired a whole core and a quad combo log data in one pilot hole, along with triple combo logs on several wells. Further integration was done with high-resolution core GR and core analysis data to calibrate GR markers, redefine landing and steering targets improving real-time interpretation and drill wells with higher in zone percentages. Horizontal wells in thin laminated targets also present a challenge for hydraulic fracture initiation and optimization. We conducted detailed fluid sensitivity studies on cuttings from wells across the basin to optimize the fracturing fluid recipe minimizing any formation damage. Rock types with low clay volumes were found to be the least sensitive, highlighting the importance of steering the lateral in cleaner sand intervals. A calibrated pre-job geological model along with a systematic approach to support geosteering decisions and a tailored fluid chemistry for completion optimization was critical in overcoming challenges in these complex reservoirs.

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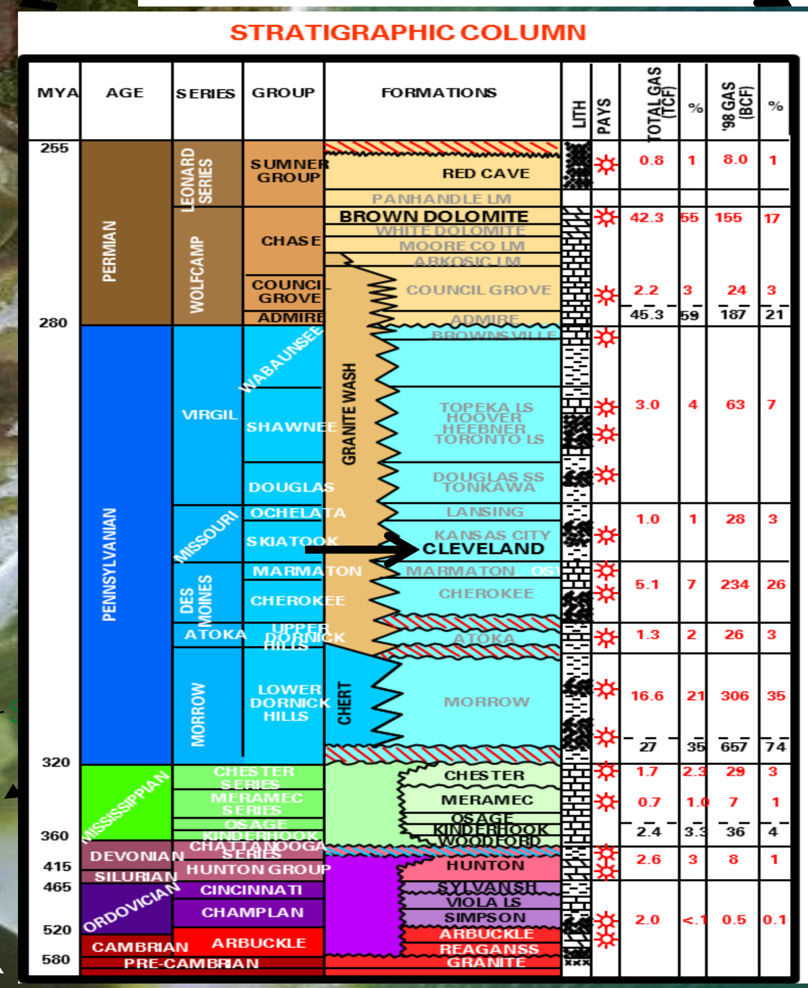
Outline

- Objective
- Depositional setting (Facies description)
- MWD vs Open hole log comparison (Thrubit)
- Improvements in targeting and steering (Well A-> Well B-> Well C)
- CST (Capillary Suction Test) improvements
- Summary

Depositional system

Cleveland sands, Anadarko Basin (TX Panhandle-OK)

- Fluvial Deltaic deposition
- Tidal reworking
- Stratigraphic trap
- 20-80 ft net reservoir
- 3 – 15% porosity
- 0.004-0.04 mD
- Volatile oil to retrograde system



Well A

Poorer in zone percentages, high degree of uncertainty in target identification

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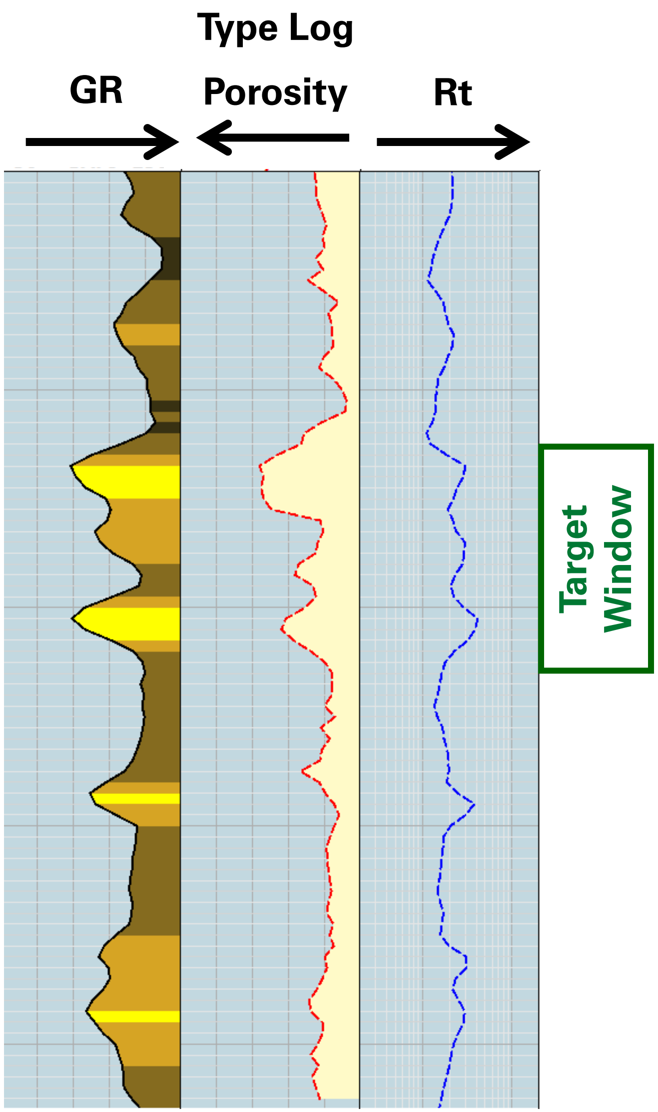

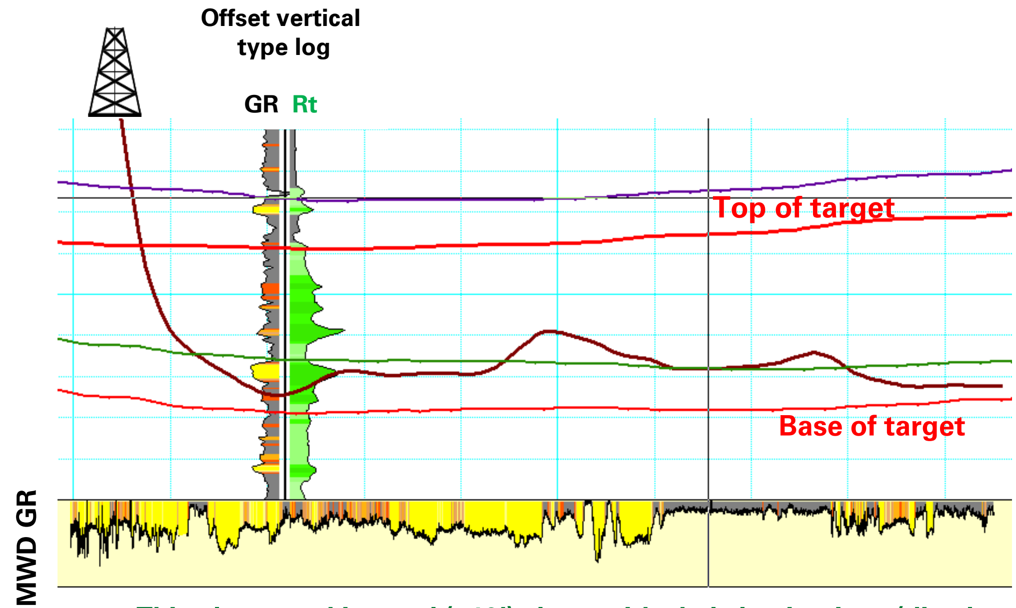

Thin clean sand interval (~10') along with shale laminations (distal bodies) make it hard to find and stay in the reservoir

Well A

- Lateral discontinuous sand bodies
  - Tidally reworked sands (sand shale laminations)
- *Higher GR values seen in horizontal wells compared to offset vertical type logs*
- *Steering based on top of structural markers*
- *Target windows at ~400' intervals*
- <40% lateral in clean sand

Differences in GR

MWD GR from three different MWD vendors vs ThruBit (post drilling)

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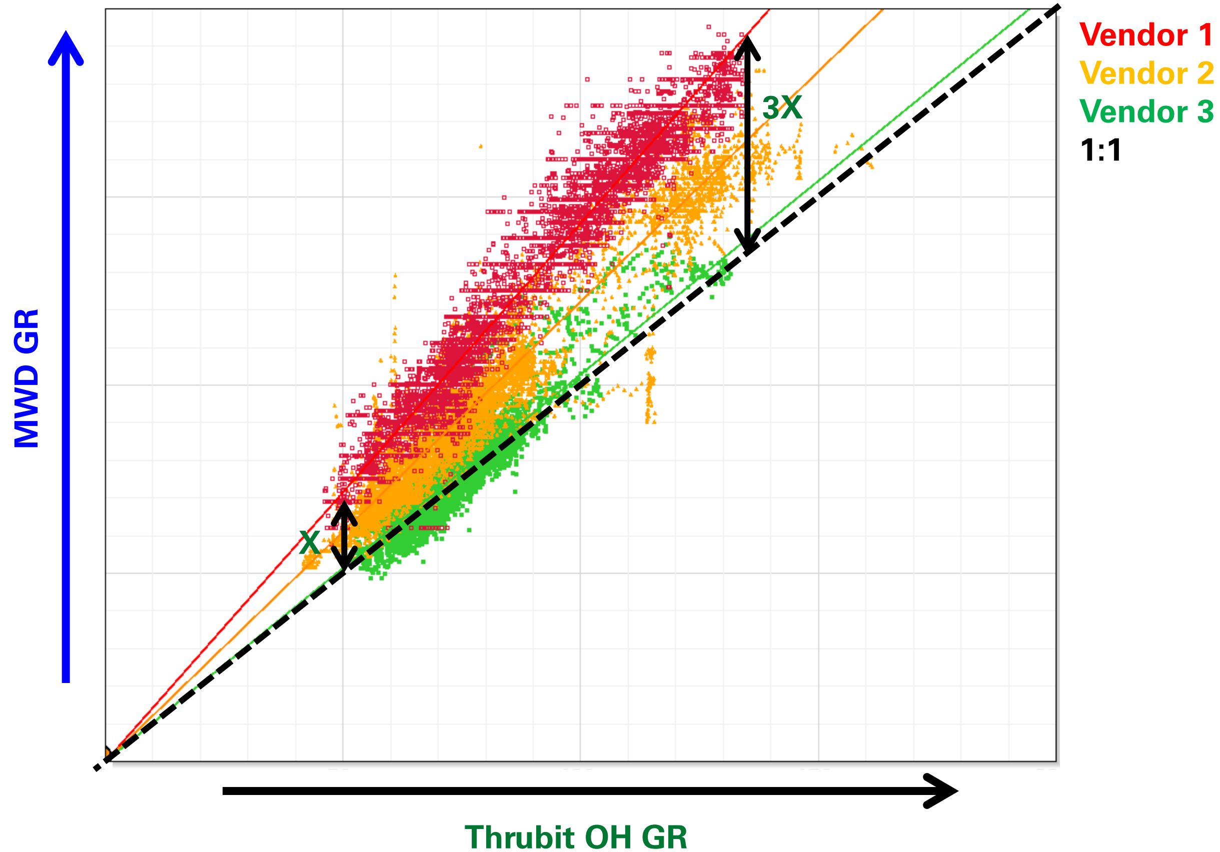

- MWD GR coming from multiple horizontal wells, 3 vendors, varying rock quality
- Increased separation with increase in shaliness (higher GR)

Possible reasons for GR differences

MWD vs Open hole ThruBit logs

- Improper tool calibration
  - *Diverse calibration techniques among different vendors*
  - *Different environmental corrections*
- Thinly bedded/laminated reservoirs
  - *Tool reading may be affected by the formations above and below the well bore in laminated reservoirs*
  - *Azimuthal MWD GR tool can be used to understand these variations better*
- Borehole conditions (while drilling vs post drilling)
  - *Drill cuttings circulation may affect the statistical counts*
  - *Radioactive mud (KCl)*

Lithofacies from a whole core in AOI

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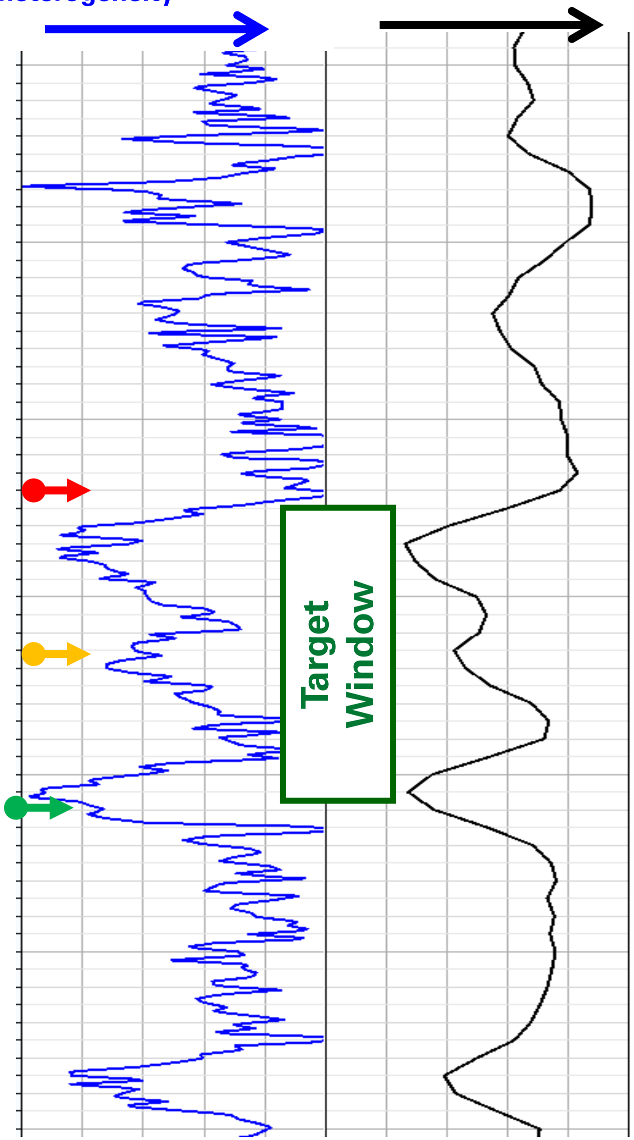
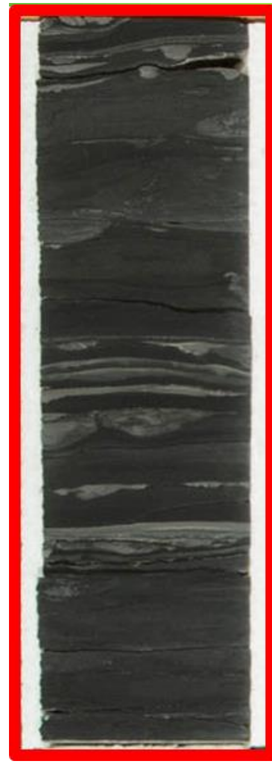
High Resolution Core GR
- 6 times OH WL sampling
- Better understanding of heterogeneity

Poor resolution Wireline GR
- Robust understanding of heterogenity





Proximal-distal delta front

Clay rich interval

(drilling & completion hazard)

Tidal mouth bar

Thin, ripple stratified and lenticular v. fine grained sandstones interbedded with argillaceous siltstones

Distributary channels

Wavy bedded, ripple stratified, very fine grained sandstones

(Target interval)

Well B

Improved Steering, Entire lateral delivered in thin target zone

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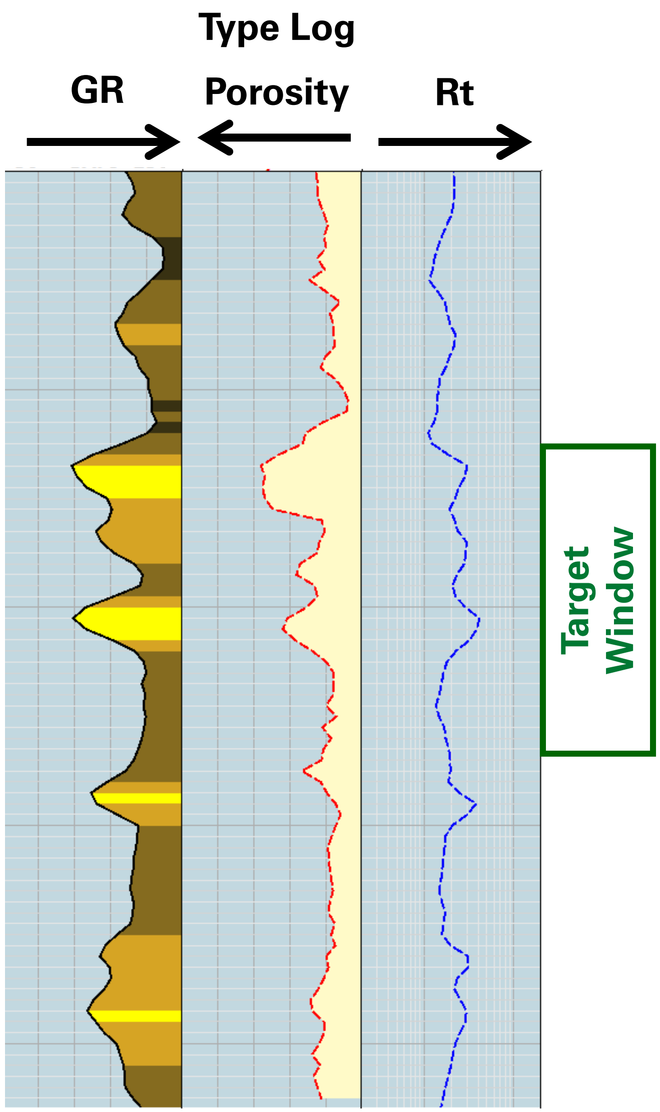

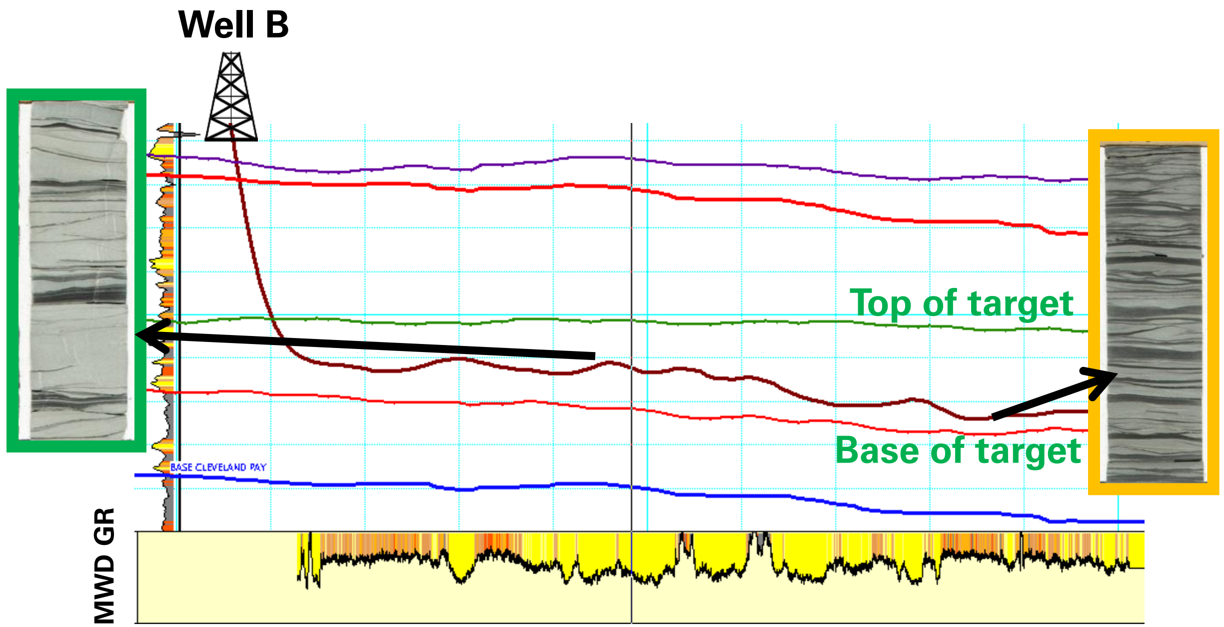

Well B

- *Understand local stratigraphy to deliver lateral in best available rock*
- *Steering based on top of target sand instead of structural tops*
- *Calibrated MWD GR; improved understanding of vertical and lateral heterogeneity*
- *Target windows at ~400' intervals*
- >90% lateral in clean sand

Well C

Current steering strategy: Isopach maps along with local X-sections provide a complete picture

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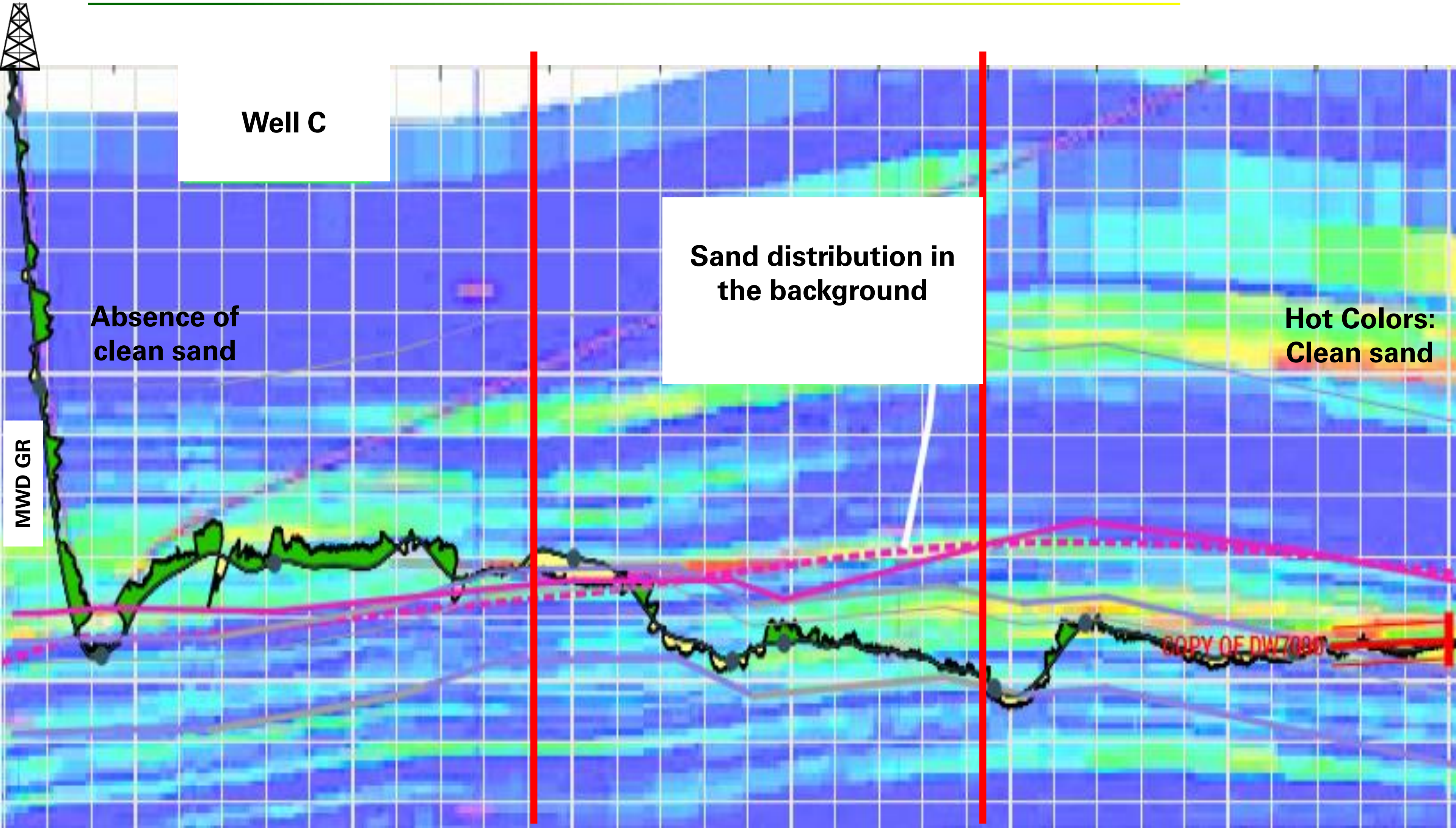

Geological model in the background helps make better real time steering decisions and also helps in planning your stages better

Improved well placement

Program results consistent after learning curve

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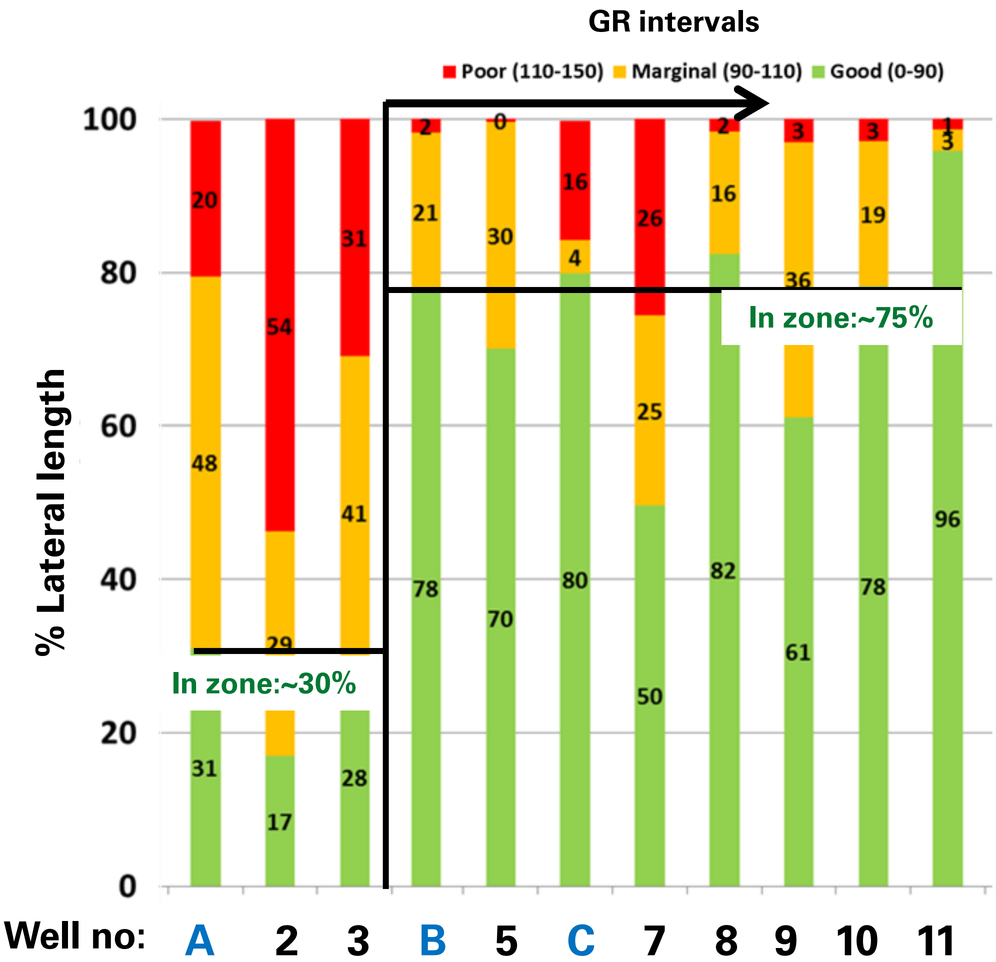

- Higher in zone percentages
- Fewer operational issues
- Faster drilling and completion
- Improved economics

Mineralogy

XRD measurements on cuttings from laterals for regional wide reservoir characterization

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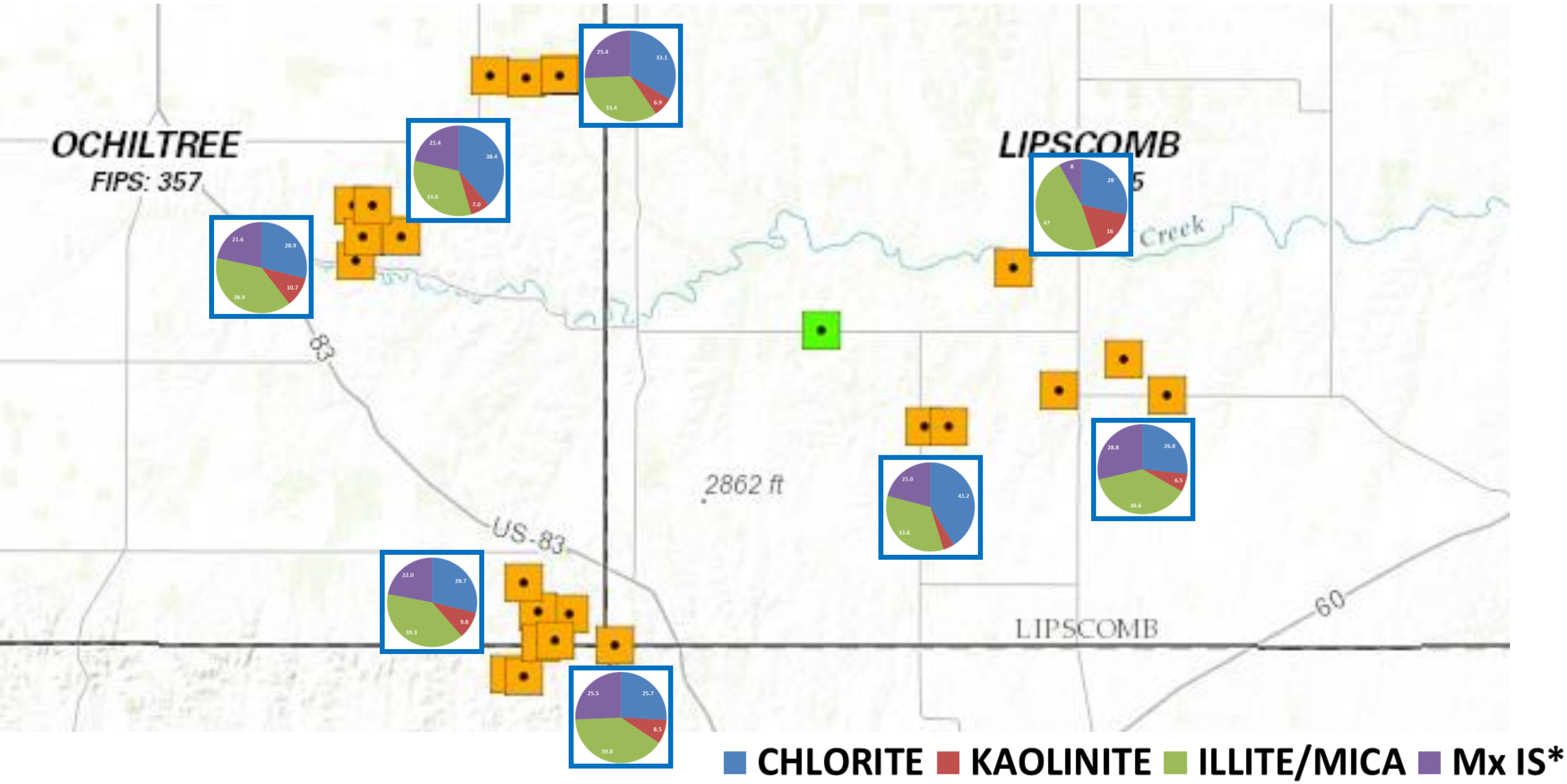

- Mixed Illite-Smectite are the dominant clay types- consistent across AOI. Being problematic (swelling) clays, identification of formations sensitive fracturing fluid is key.
- Avg.Clay (%vol): 19- 35 %

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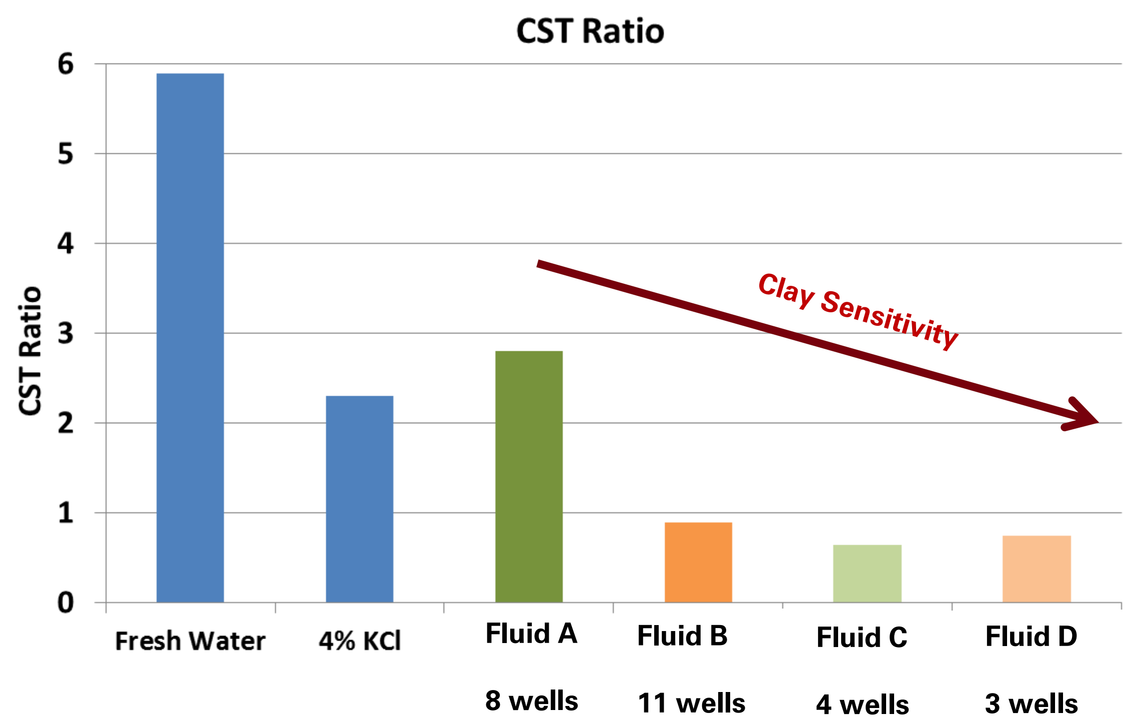
Fluid Sensitivity tests on cuttings

- 25+ fluids tested on cuttings from 8 wells
- CST (Capillary Suction Time) analysis becomes critical in clay rich intervals
  - Higher the formation sensitivity -> Higher the CST ratio -> poorer well performance (porosity reduction due to clay swelling)
- 2-3 fold drop in sensitivity from the initial frac fluids
  - Less sensitive fracture fluids -> Lower CST ratio -> improved fluid recovery and well performance



Capillary Suction Time Test measures the relative flow capacity of a slurry of ground formation rock used to form an artificial core and it is an indication of clay swelling.

* CoreLabs

CST ratio: $[CST_{sample} - CST_{blank}]/CST_{blank}$

Impact of completion fluids on production

Fluid A, C have the lowest CST ratio, improved frac fluid flowback and oil recovery

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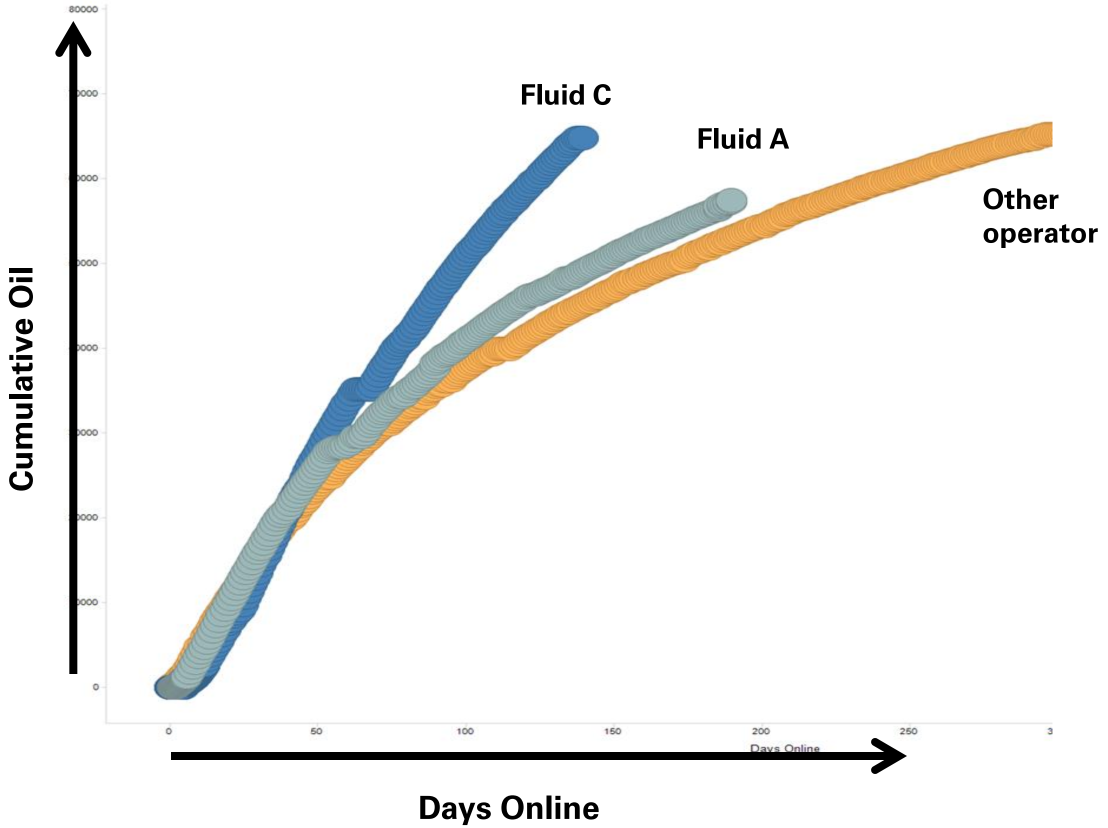

- Three wells drilled in the same section of similar reservoir quality
- Improved flowback and oil recovery were observed when the least sensitive fluid was used
- Major improvement can be seen in the long term production (after 2 months mark)

Summary

Reservoir targeting and completion improvements

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1. **Structural and Stratigraphic Control**

   FROM ➔ Steering against regional structure and reacting to stratigraphic changes

   TO ➔ Mapping specific local markers closest to target sand for better structure

2. **Logging Tools and Data Acquisition**

   FROM ➔ Difficulty trusting MWD GR values to identify target sand

   TO ➔ Robust calibration of MWD to ThruBit logs

3. **Software and Toolkit**

   FROM ➔ single well model

   TO ➔ multi-well model with 3D model input (improved targeting & higher in-zone %)

4. **Fluid sensitivity tests on completion fluids**

   FROM ➔ vendor suggested fluids

   TO ➔ formation specific, clay sensitive fluids (Better flowback and production rates)