Active Geosteering Strategies in Structurally Complex Niobrara Unconventional Reservoirs*

Mark Odegard[1], John Daniels[2], James Huck[2], and John Forster[2]

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[1]Geology, Whiting Oil & Gas Corp., Denver, Colorado, United States (marko@whiting.com)
[2]Geology, Whiting Oil & Gas Corp., Denver, Colorado, United States

Abstract

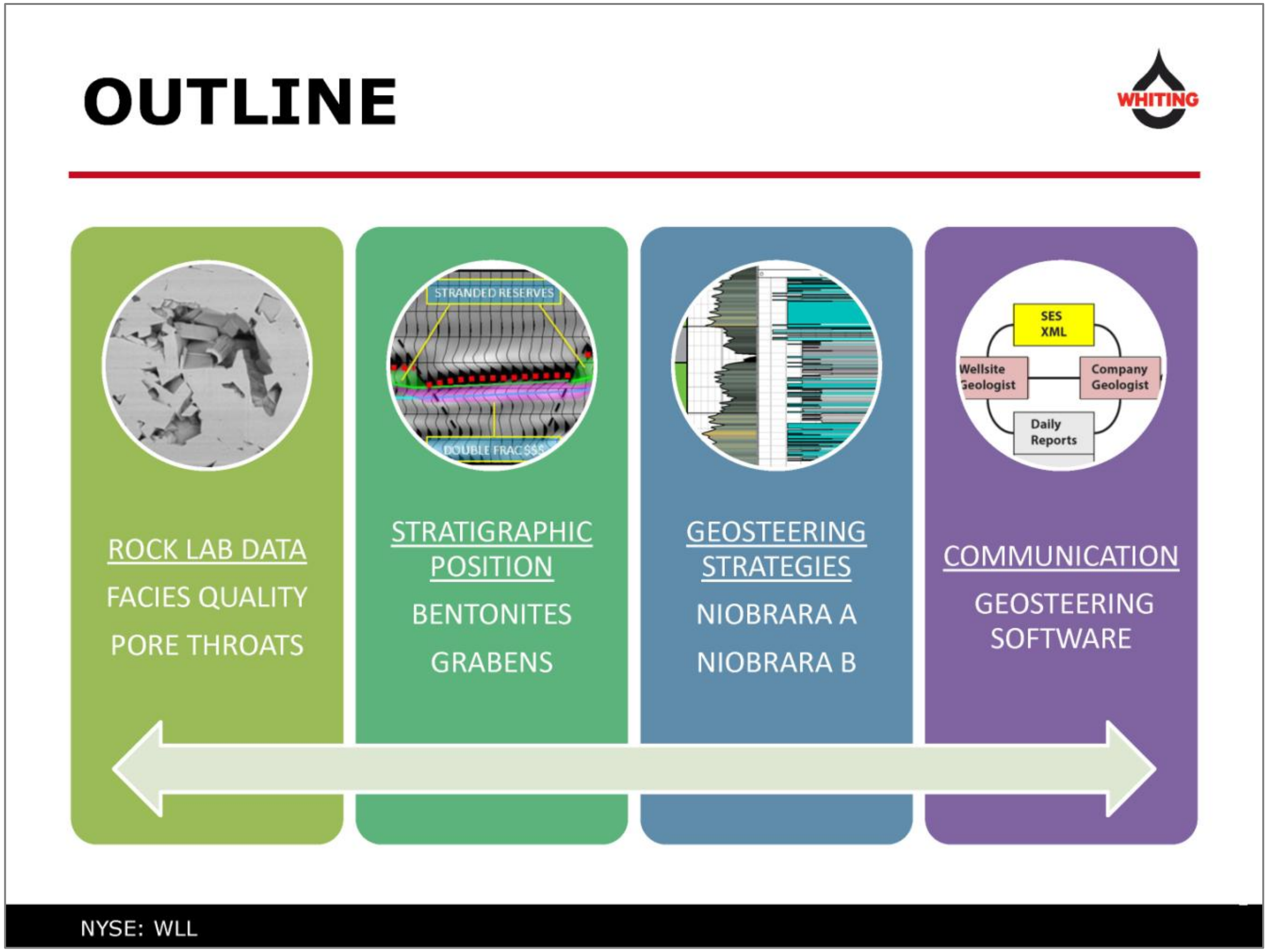
The Niobrara is a structurally complex reservoir that requires a multi-disciplined geosteering approach to achieve optimum well placement and maximize return on investment. A successful well plan strikes a balanced approach that not only incorporates the geologic goals of the well, but also takes into consideration factors that affect the operational efficiencies of both the drilling and the stimulation. When Whiting entered the Niobrara play, our geosteering was based primarily on gamma LWD logs. While this approach was somewhat effective, it became evident that the wellbores were not maximizing contact with the most brittle Niobrara chalk layers. As a consequence, Whiting's geosteering philosophy evolved from a passive or “reactive” gamma-based methodology to a proactive “forward-looking” approach to geosteering. Anticipation of, rather than reaction to, structural features would be critical for success. Whiting was able to make this shift in geosteering philosophy, due to the acquisition and interpretation of over 700 square miles of 3D seismic data. A detailed review of early wells using the new 3D seismic volume yielded several compelling observations. Primarily, it exposed an under appreciation of localized structural complexity internal to the Niobrara and an overreliance on regional structure as a guide to geosteering. The structure was much more complex than initially thought, with numerous narrow graben features with highly diverse orientations presenting new challenges for each drilling-spacing unit. A secondary observation was that wells which had the greatest number of frac stages placed in the clean chalk facies had the best individual well performance. Conversely, wells spending a significant amount of vertical section in the marls generally performed more poorly. This trend is likely due to the reduced efficiency of the stimulations in stages that were placed in the more ductile, bentonite-rich facies of the Niobrara. Whiting's current geosteering strategy utilizes a series of TVD and VS waypoints to give a best-fit wellbore path based on 3D seismic interpretation, facies mapping, offset well data, and

optimum drilling parameters. Narrow grabens are “speared through” without inducing excess wellbore tortuosity. These factors must be considered when employing an active geosteering strategy in a structurally complex unconventional reservoir.

Whiting Petroleum Corporation
and its wholly owned subsidiary
Whiting Oil and Gas Corporation

Active Geosteering Strategies in Structurally Complex Niobrara Unconventional Reservoirs

Mark Odegard- Senior Geologist



Presenter's Notes:

- **ROCK LAB**
  - Brief tour of the Whiting Rock Lab
  - **Type of analyses** that can be done in-house
  - We'll look at a regional type log and generalized **facies descriptions**

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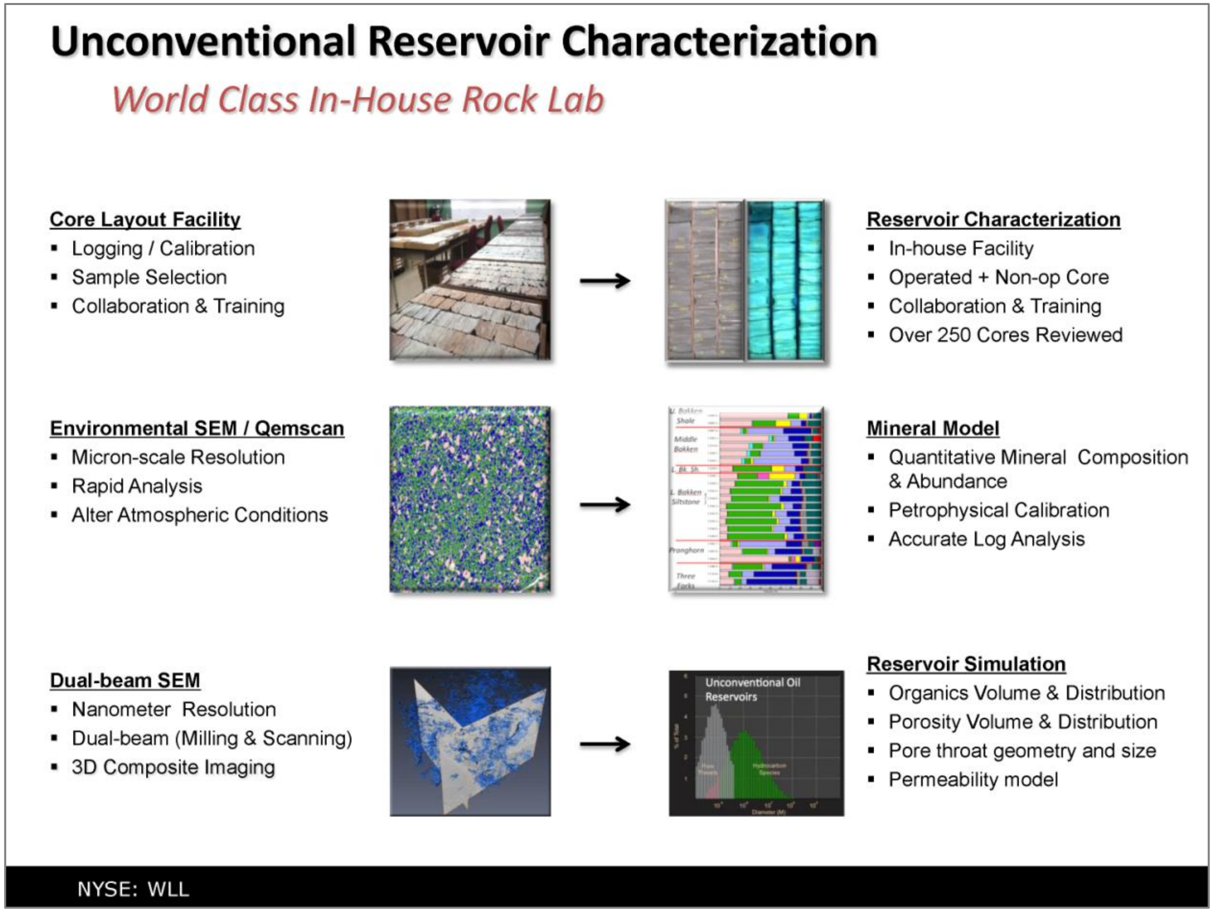
    -
    - Then we'll examine the differences in **reservoir quality**
    - **Niobrara Chalks vs. Marls**
    - Distribution of Hydrocarbon **Molecule Sizes**
    - Compare that to our **Pore Throat sizes**

- **BENTONITES**
    - Where they are present in the stratigraphic column
    - **Unconfined Compressive Strength**
        - Bentonites vs. Chalks
    - Demonstrate their negative impact on **proppant placement**

- **STRUCTURAL COMPLEXITY**
    - **Frame the scale** of the problem in a fun way
    - **Magnitude of the Faults vs. Thickness of our target zones**
    - PreStack Depth Migration **(PSDM)** 3D seismic volume

- **GEOSTEERING STRATEGIES**
    - HOW WE USE THE FACIES, BENTONITES AND STRUCTURAL DATA TO DRIVE OUR GEOSTEERING METHODOLOGY
    - **Zone specific** examples

- HOW WE TIE IT ALL TOGETHER WITH **GOOD COMMUNICATION** WITH OUR WELLSITE GEOLOGISTS



Presenter's notes:

Reservoir Characterization

- Typelog showing
    - Gamma Ray
    - Deep Resistivity
    - Density Neutron
    - the informal names of the Smoky Hill and Beecher Island members of the Niobrara

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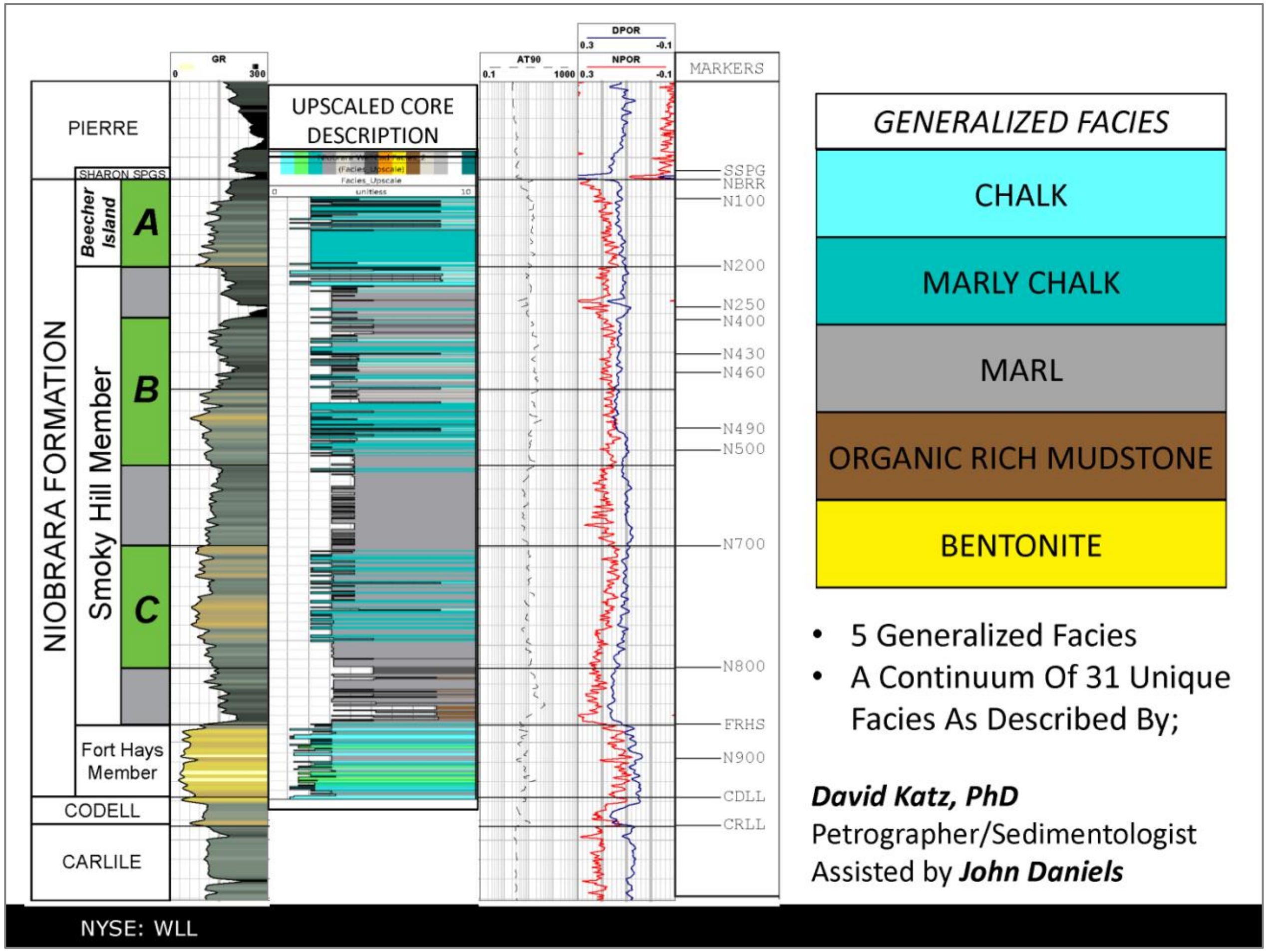
- Intera Markers on the right (Mark Longman, Susan Landon and Barbara Luneau)
- 5 easily recognized facies in the Niobrara
    - Chalk
    - Marly Chalk
    - Marl
    - Organic Rich Mudstone
    - Bentonite
- **Five years and 2,000'+ of Niobrara core descriptions**
    - David Katz and John Daniels have identified a <u>complex continuum of 31 distinct facies</u>
        - 2ft upscaled core description shows the interbedded nature of these facies
    - **The distribution of these facies effects our geosteering strategy, which varies by zone**



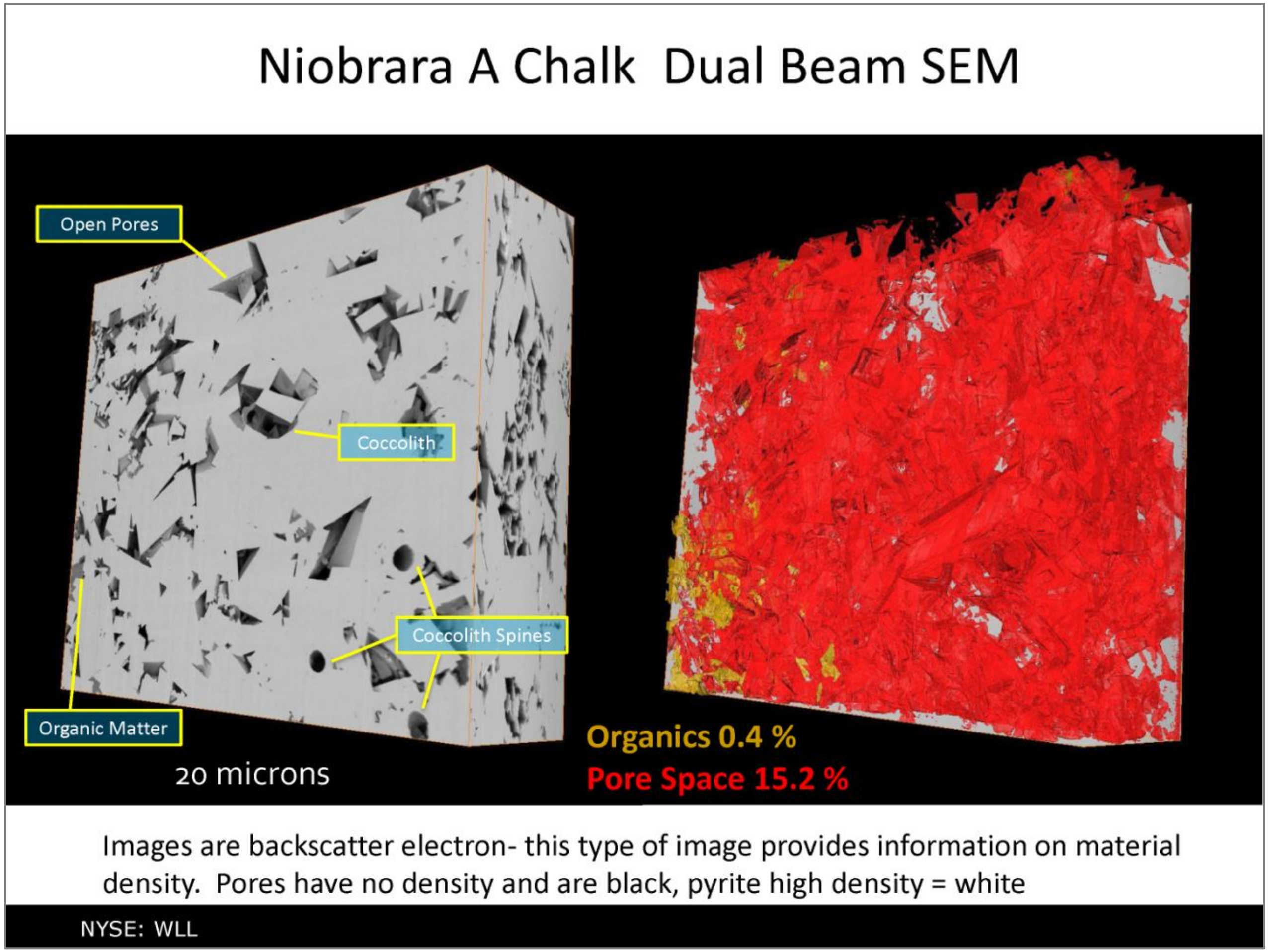
Presenter’s notes:

- **<u>Dual Beam Scanning Electron Microscope</u>**
    - This **20 micron example** is from the **Niobrara A Chalk**
    - Image is a backscatter electron display
        - Provides information on **material density**

(Presenter’s notes continued on next slide)

(Presenter's notes continued from previous slide)

    - Pores have no density, and are black
    - Chalk and other constituents are greys
    - Pyrite is white, very dense
- **Dual Beam**
    - **Milling & Scanning**
        - Segmentation of components (mineral, pore and organics)
        - allows us to perform **digital rock physics,**
            - calculating attributes like
                - **Permeability**
                - **Porosity**
                - **Pore throat sizes.**



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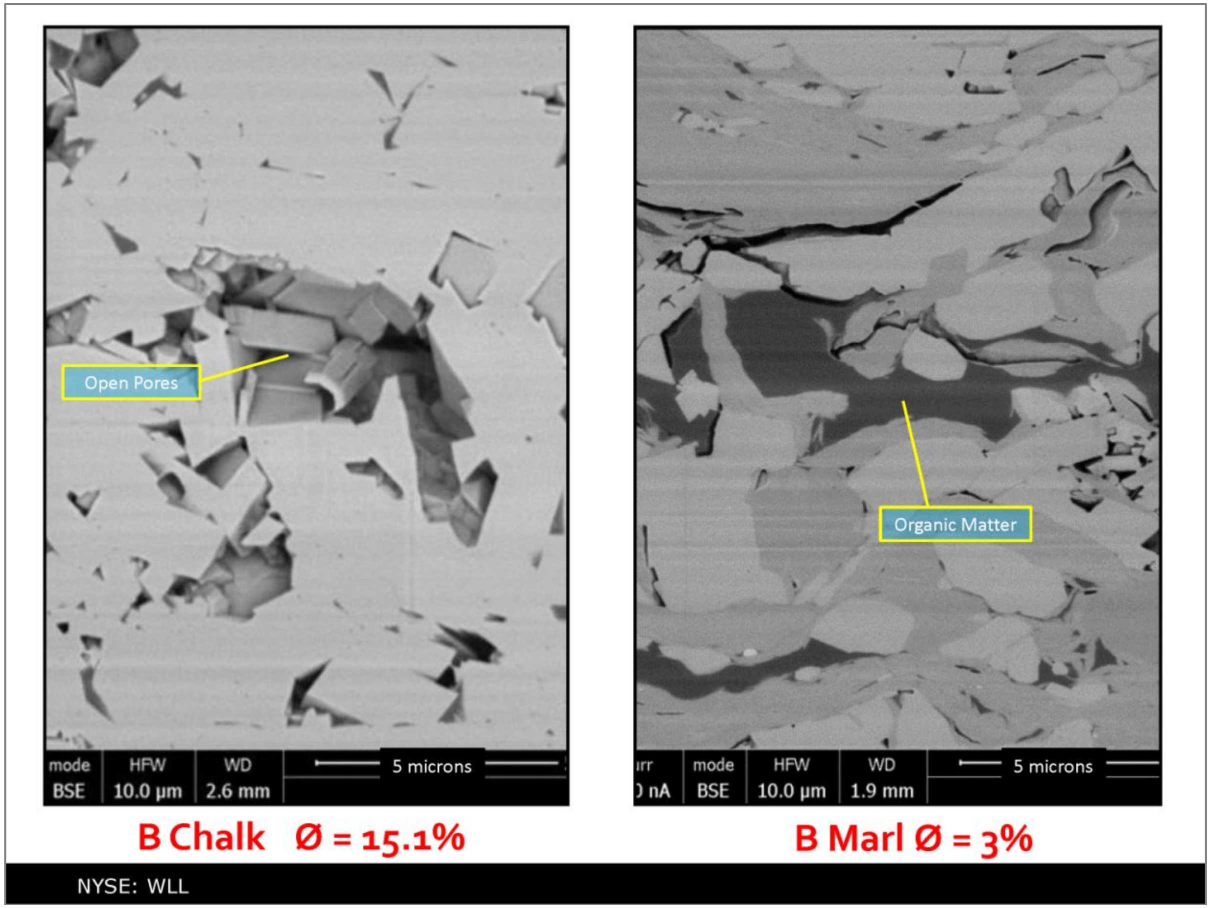

Presenter's notes:

SEM IMAGE COMPARING B CHALK TO B MARL

Zooming in to a 5 micron sample now

- Niobrara B Chalk
    - >90% Calcium Carbonate (CaCO3)
    - >15% porosity
    - Large Pores and pore throats

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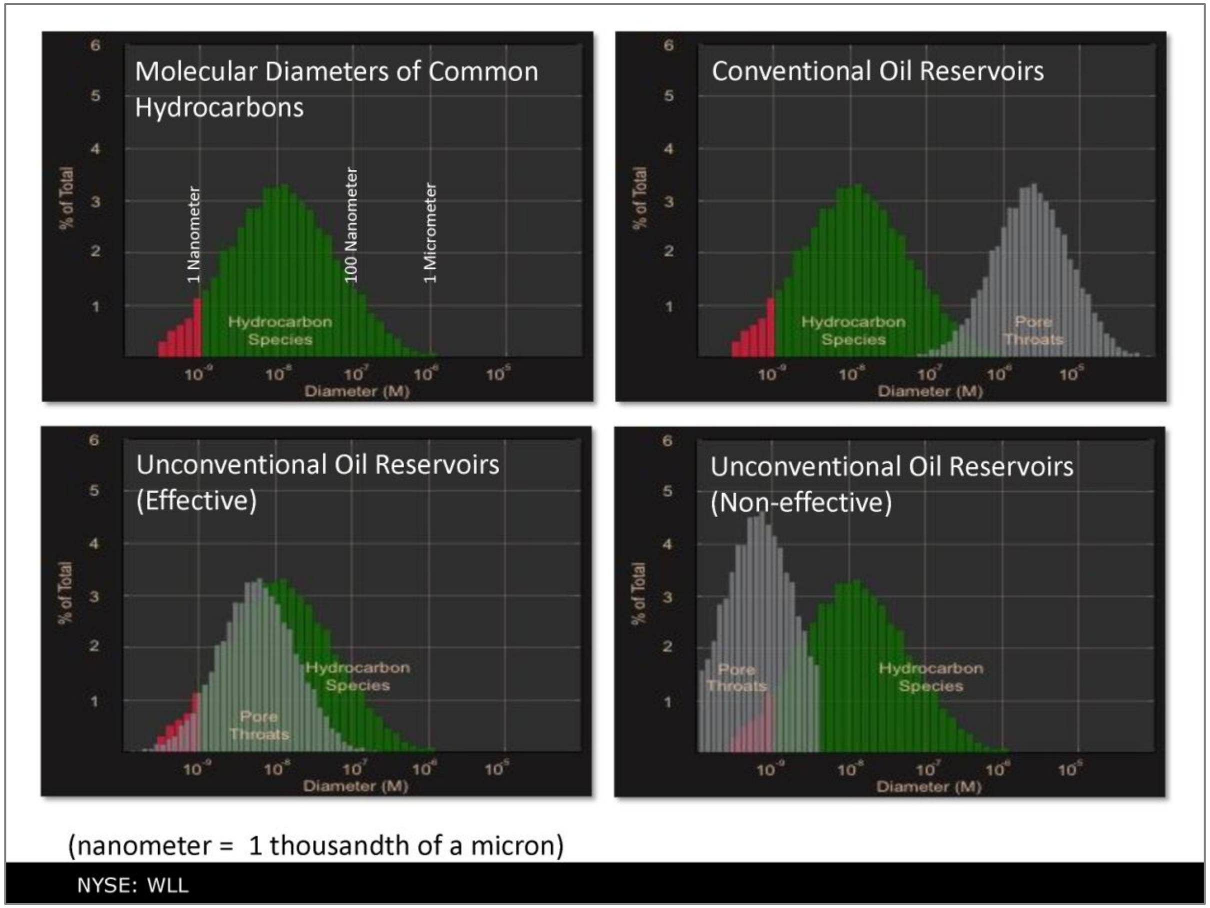
- Niobrara B Marl
    - Also contain Calcium Carbonate ($CaCO_3$)
    - but also contain varying percentages of;
        - clay
        - quartz
        - organic matter
    - **Only 3% porosity**

- Facies Matter
    - This impacts our geosteering strategies
    - The goal is to geosteer our well in such a way as to place as many frac stages in the most porous/permeable rock as possible
        - Conductivity is king over the life of the well



Presenter's notes:

PORE THROAT AND MOLECULAR SIZES

- The key to exploiting unconventional reservoirs
    - **right product type in the appropriate geologic conditions**, as we can see from this comparison of the molecular size of the hydrocarbon species

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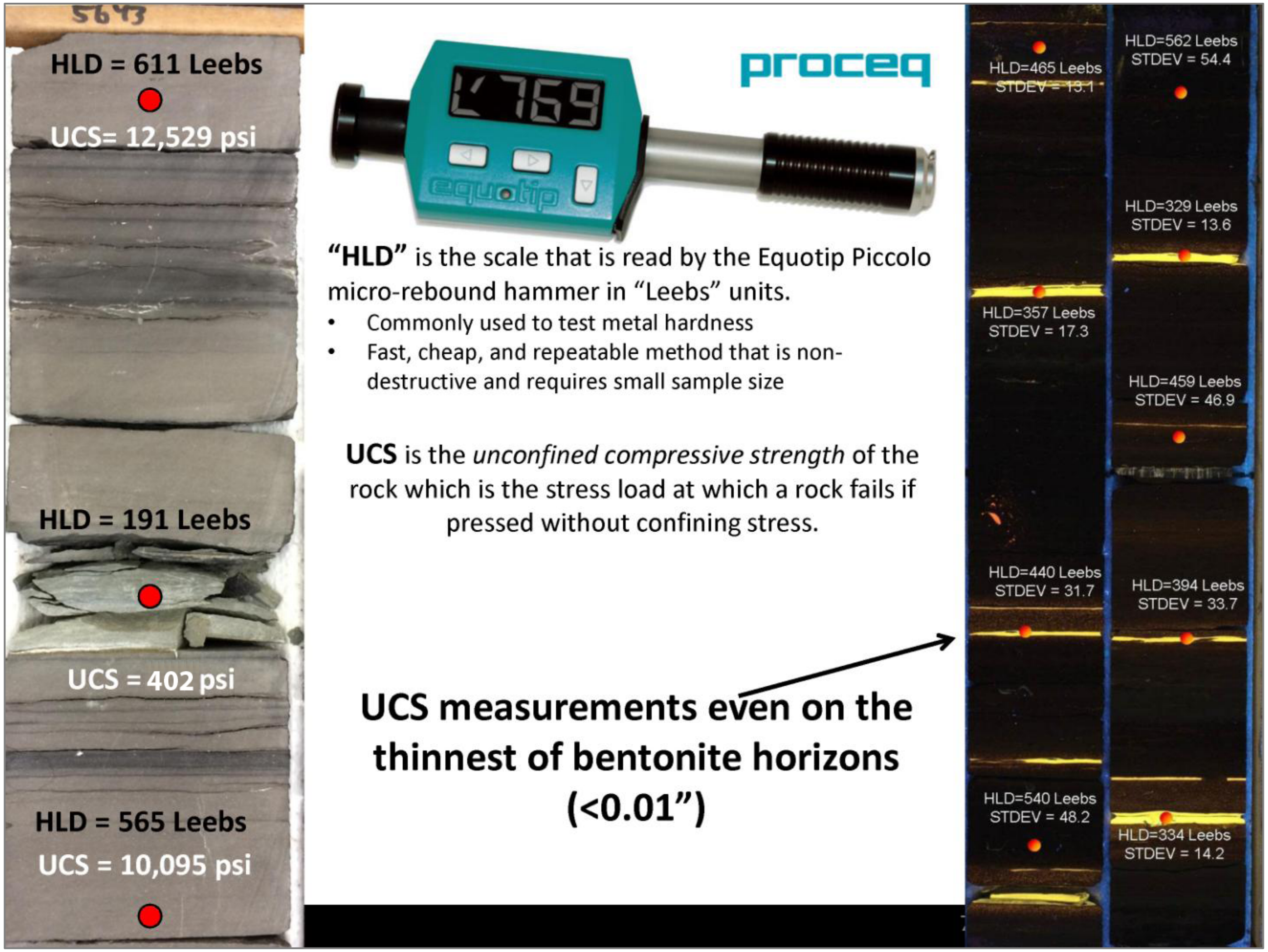
- Common hydrocarbons range in size from roughly 1 to 100 nanometers in size

- **Conventional resources, the plays of the 1960’s to early 2000’s,**
  - occurred where the pore throat sizes are orders of magnitude larger than the oil molecules.
- **The Unconventional Resource Plays occur where**
  - the oil molecules are and the pore throats have similar sizes.
    - Not all the oil molecules in the system are the same size
      - when the some of the oil molecules, particularly the asphaltenes, are larger than the pore throats the reservoir becomes plugged up, similar to plaque in an artery; things just don’t flow well.
      - **In the Niobrara, this phenomenon can vary with facies**

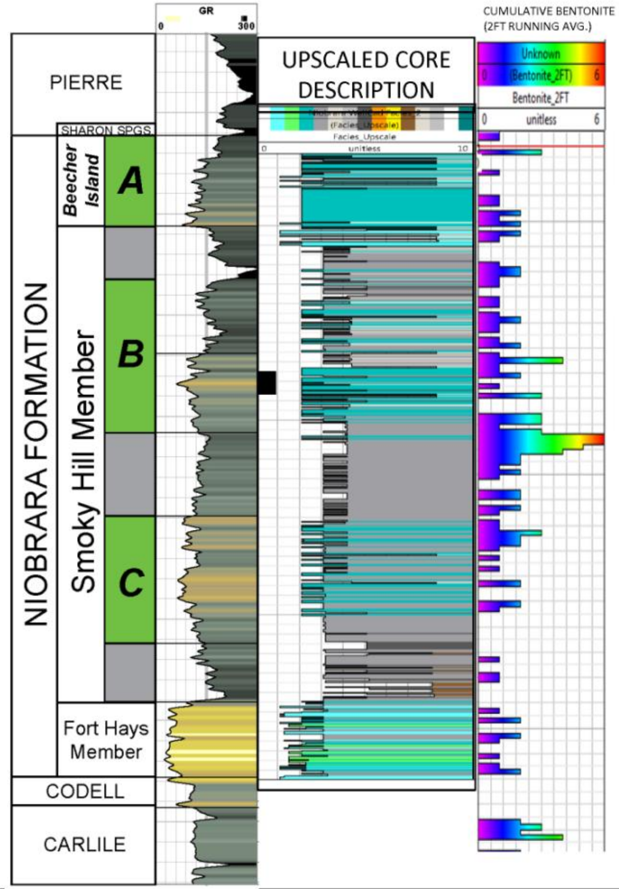
- **Computational chemistry tells us that**
  - oil molecules range in size from 2 to 10 nanometers,
  - but some species, like asphaltenes, coalesce to form much larger aggregates (up to 100nm) and are polar.
  - In the Niobrara, pore throat diameters range from 10’s of nanometers to over 500 nanometers.



Presenter's notes:

Radioactive Proppant Tracing

To confirm the mechanical heterogeneity measured by the Piccolo, a Scaled Limited Entry Frac job was performed in the best facies of the Niobrara B



Scaled Limited Entry Frac & Radioactive Proppant Tracing

- Perf'd the Niobrara 'B'
- Pumped DFIT, post-job diagnostic work
- Build fracture model, match the DFIT
- Frac & tag w/ RA tracer
- Ran spectral gamma-ray log

NYSE: WLL

Presenter's notes:

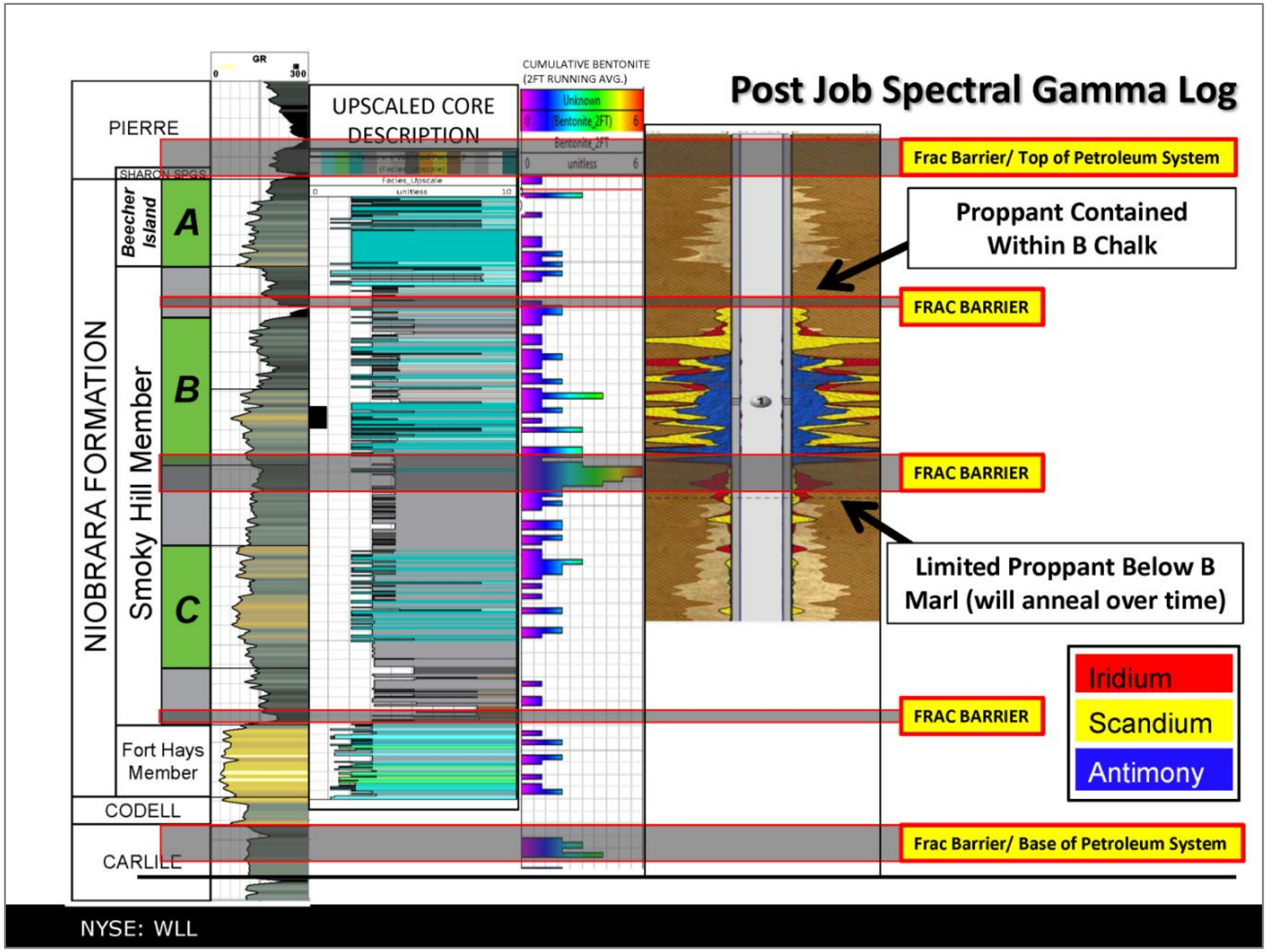
Bentonites And Proppant Placement

- The post job spectral gamma log is shown here.
- As you can see from the location of the **Iridium, Scandium and Antimony proppant tracers;**
  - The proppant is nearly **perfectly confined to the Niobrara B**

(Presenter's notes continued on next slide)

(Presenter's notes continued from previous slide)

- **The complex pathway that the frac fluid has to take to "break through" the bentonites, is too complex for the proppant to follow.**
  - That means that while the **fluid filled fractures extend above and below the Niobrara B,**
  - These fractures will **likely anneal over time**
  - **Pressure and production data support this conclusion**
- Extrapolating these results throughout the Niobrara identifies **other potential frac barriers**
  - These begin to look like **well defined "flow units"**
- Think about how this could impact your **geosteering plan…**
- **At this point in my talk, we've;**
  - **identified the where the good rock is**
  - Demonstrated that **bentonites are mechanically weak** and
    - The bentonites stratify our reserves into well-defined flow units
  - **We're ready to drill, right?**
    - Wait. We must first address the complex structural nature of the Niobrara.
    - **Warning…warning…scale change coming on the next slide… micron scale to google earth scale!!!**



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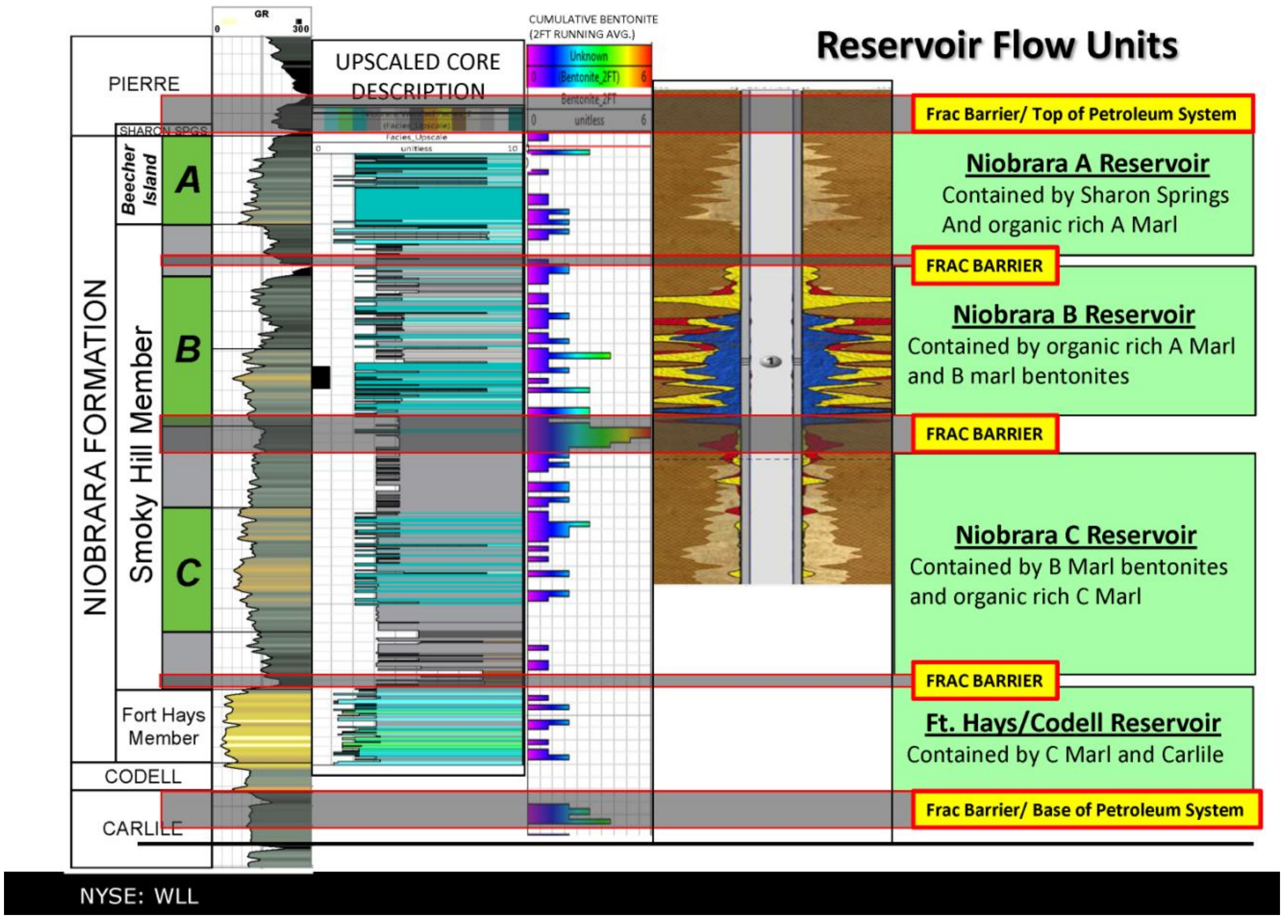

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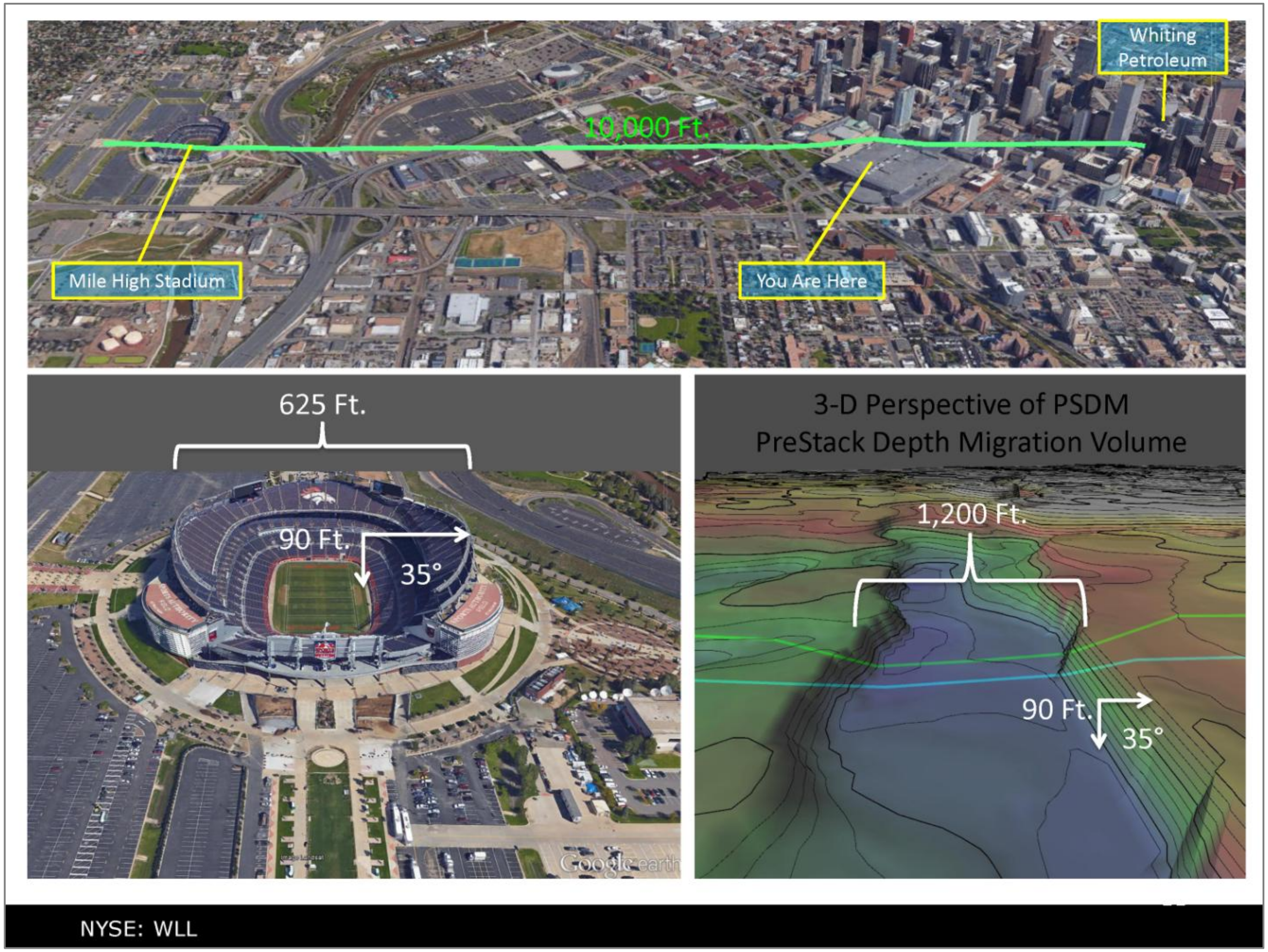
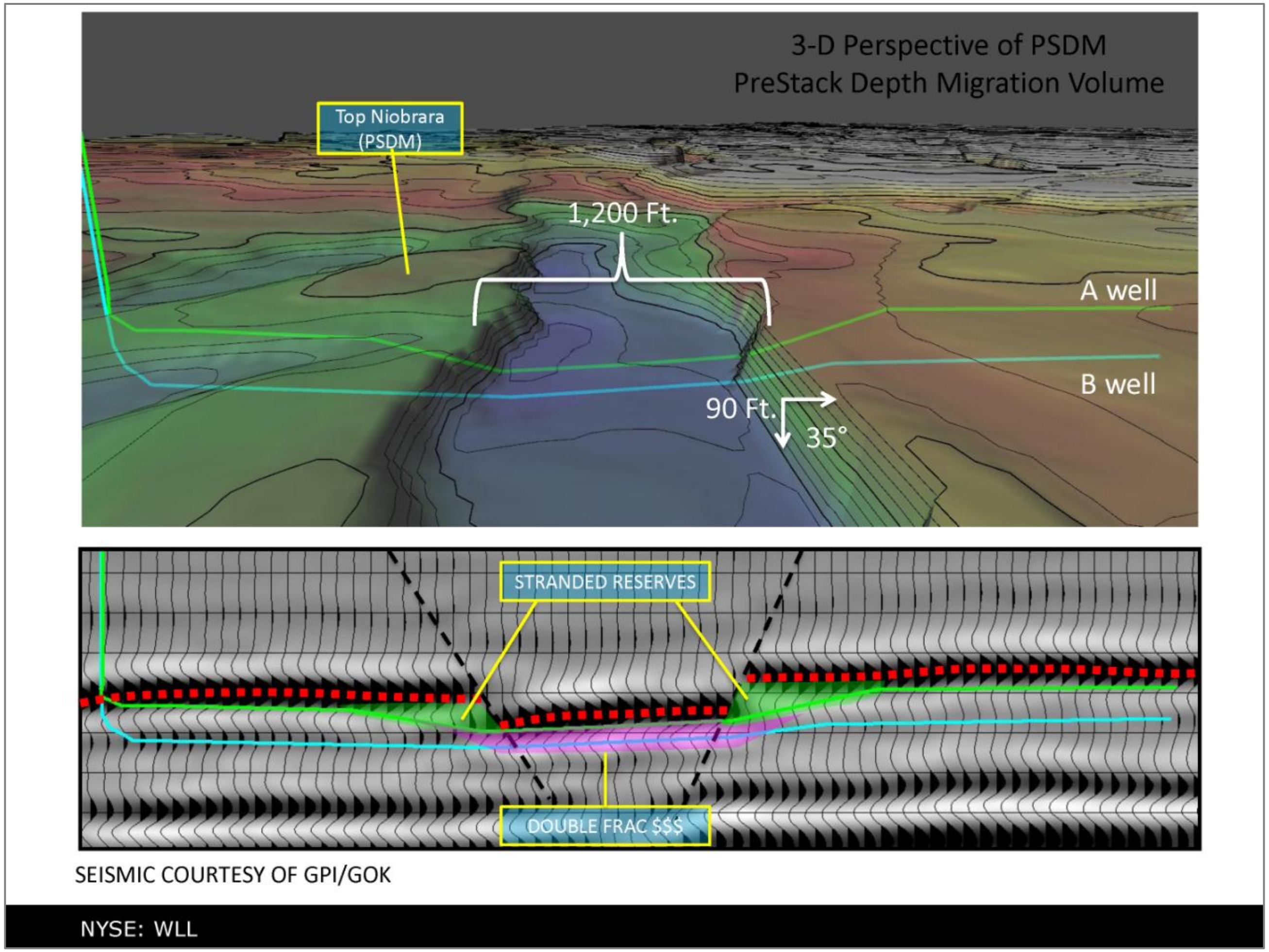


Presenter's notes:

WHAT IS THE SCALE OF THE STRUCTURAL PROBLEM?

Niobrara A Chalk geosteering target is 20ft thick.



Presenter's notes:

This is an example of our current methodology

- We aggressively map the **Lowest Known Sharon Springs**
    - Geosteer to exit the pay zone at the fault, under the Sharon Springs bentonites
    - This allows us to **frac our A zone well right up to the graben**

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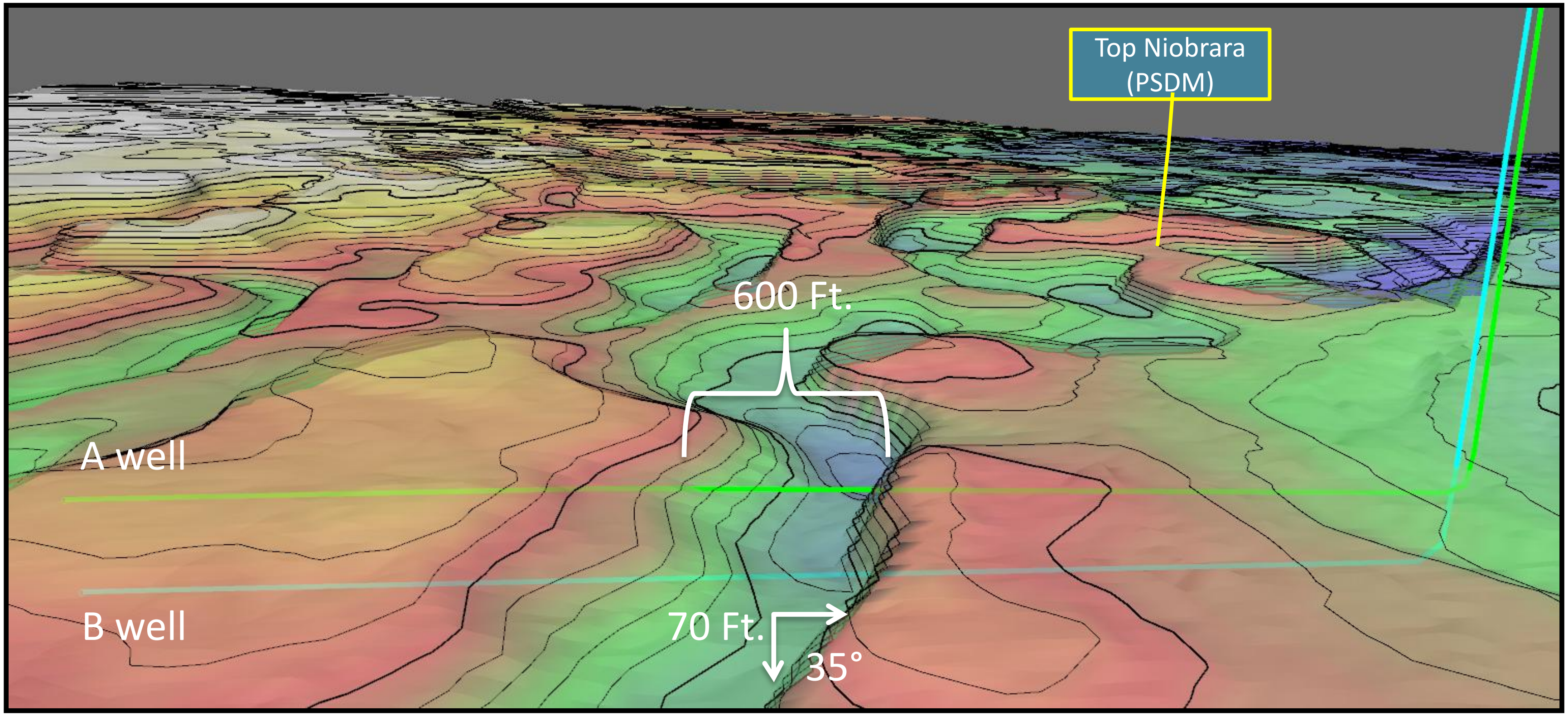
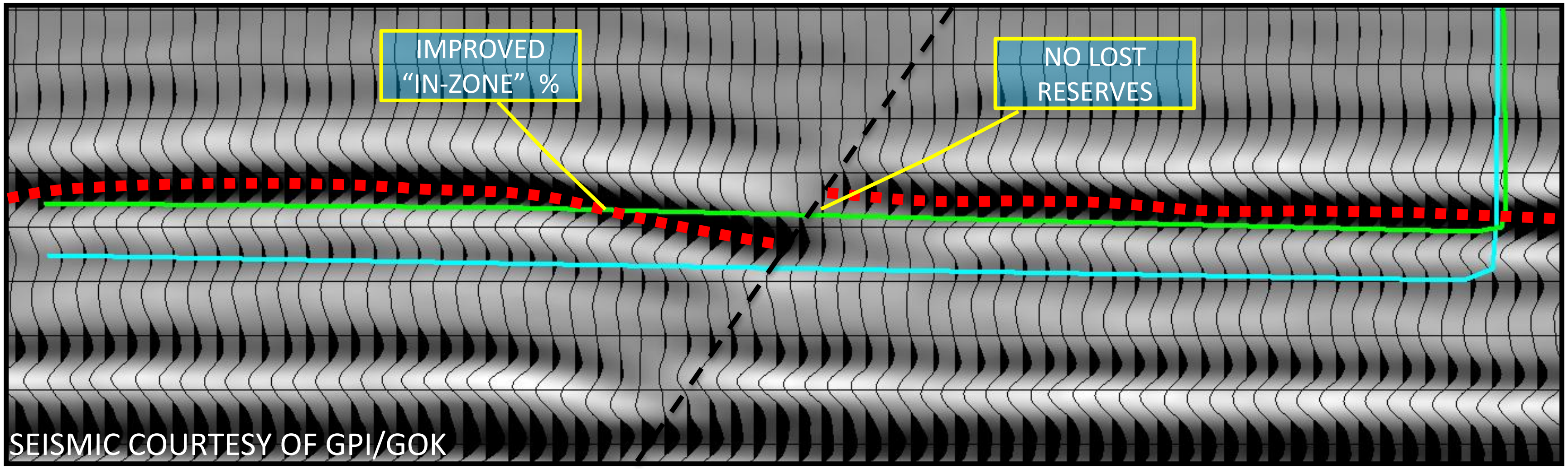
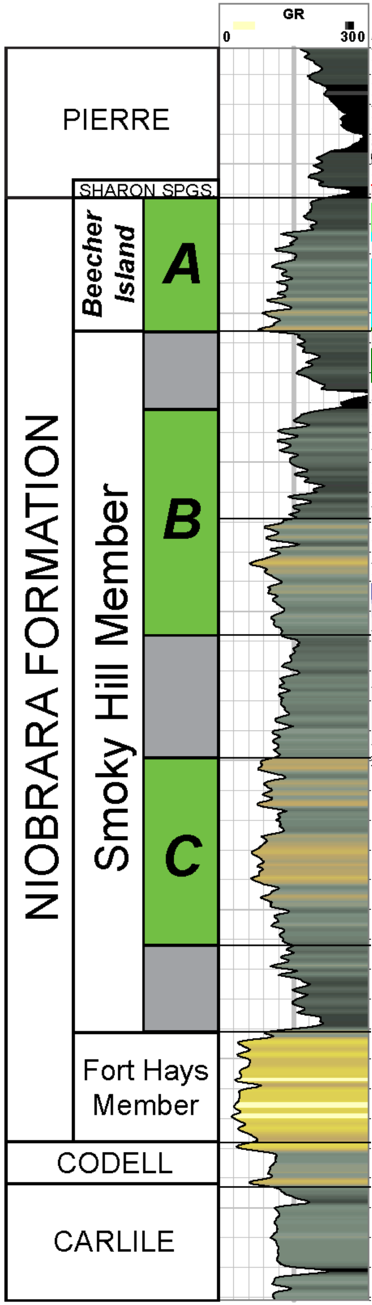
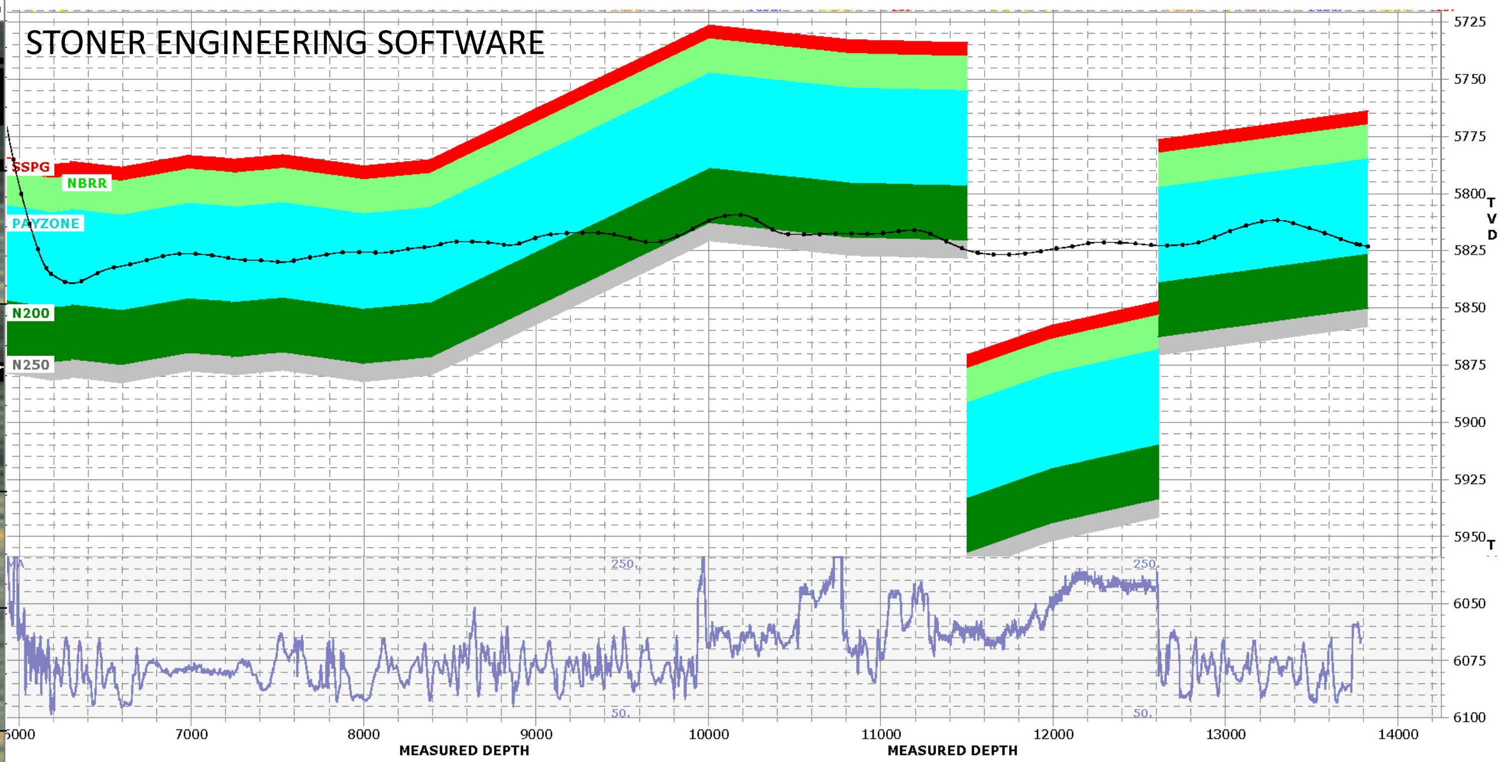
  - Re-enter the Top Niobrara while cutting through the Sharon Springs at a high angle to **limit wellbore exposure**
  - This requires excellent communication with drilling engineers and mudloggers
  - Stages above the top of the Petroleum System are skipped, saving $$$
- **We’ve reduced the negative production effects of this graben to its actual physical dimensions**
- **Previous methodology- a 600ft wide graben negatively effected 1500 ft of lateral**


Top Niobrara
(PSDM)
600 Ft.
A well
B well
70 Ft.
35°

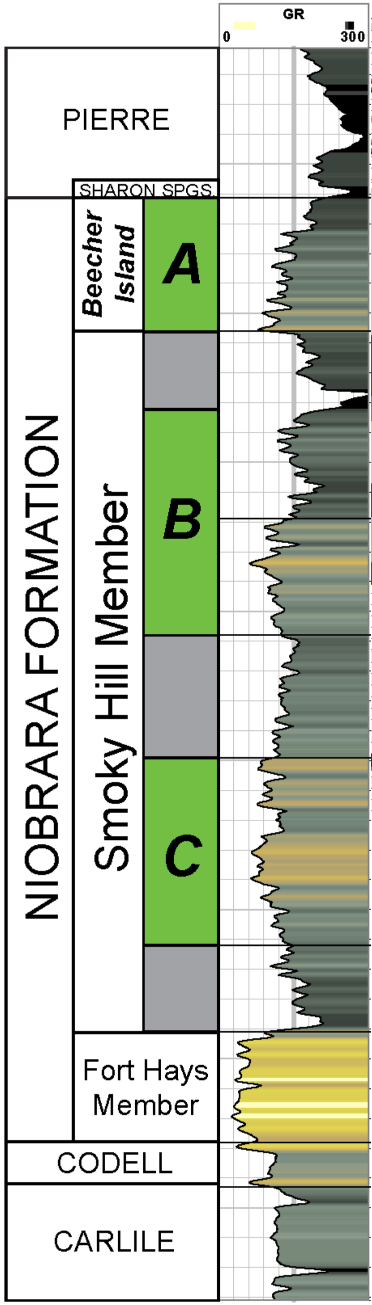

IMPROVED
"IN-ZONE" %
NO LOST
RESERVES
SEISMIC COURTESY OF GPI/GOK

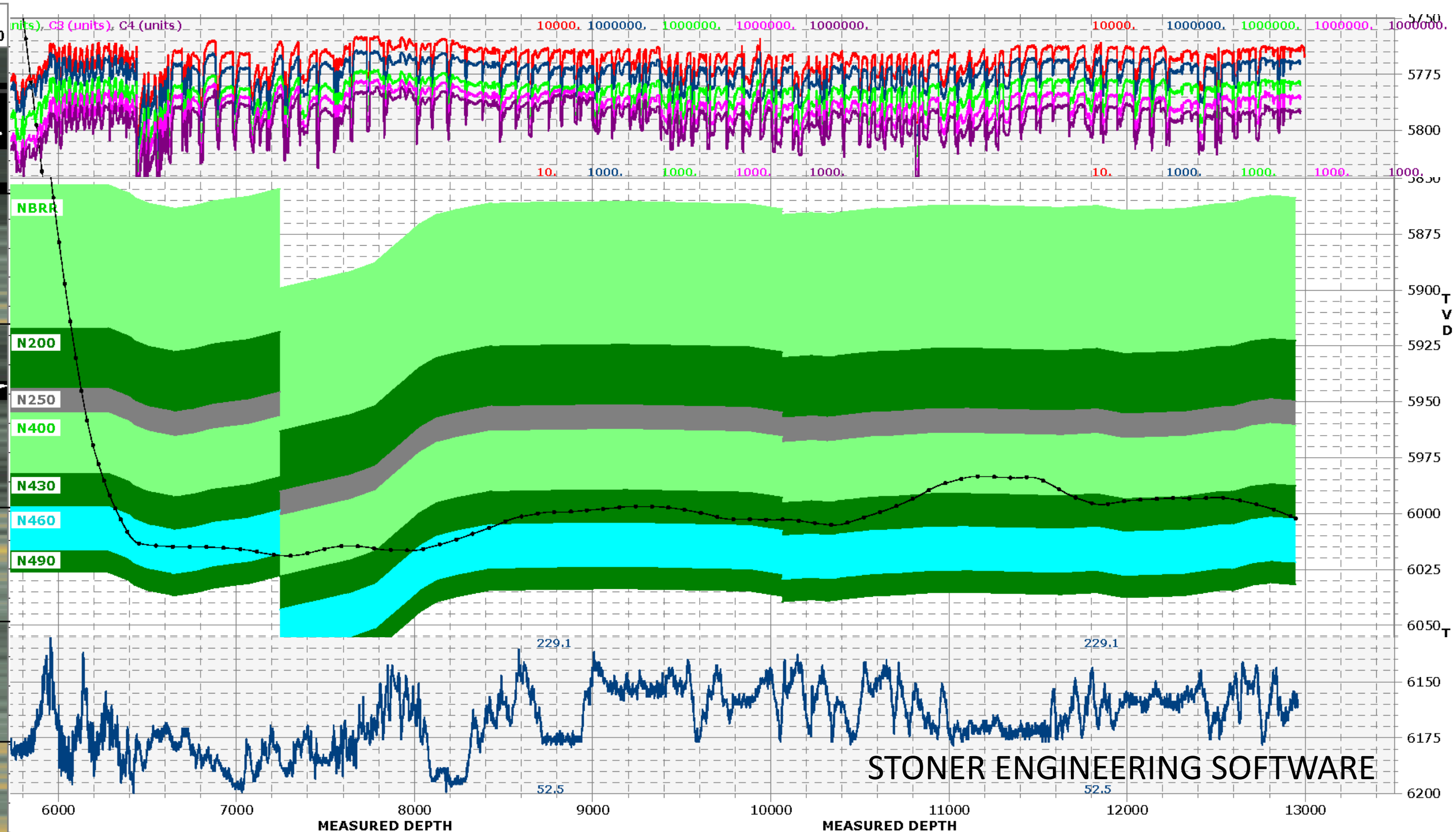




NIOBRARA A GEOSTEERING STRATEGY

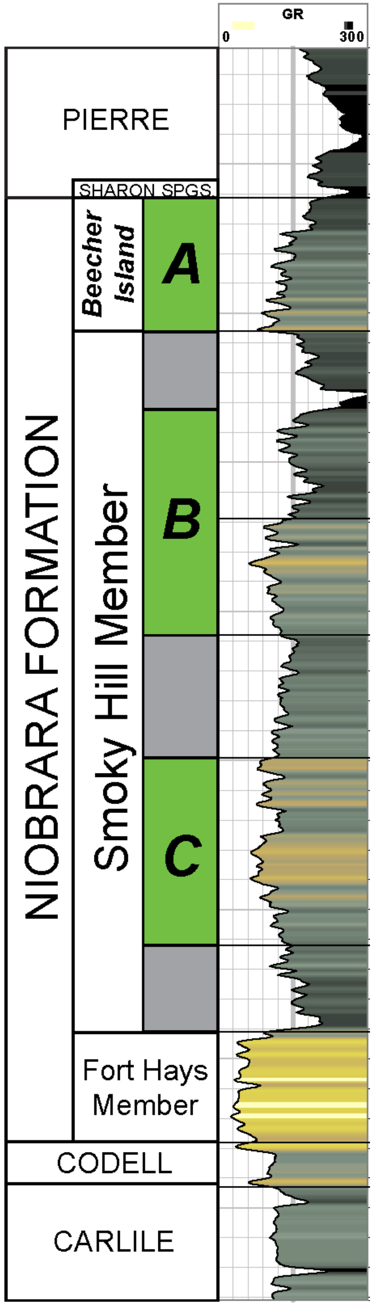
- PSDM STRUCTURE MAPPING
- FLOW UNIT BOUNDARIES
  - BENTONTIES
  - ORGANIC RICH MUDSTONES
- FACIES QUALITY
- WHILE DELIEVERING A WELLBORE THAT HAS LOW TORTUOSITY





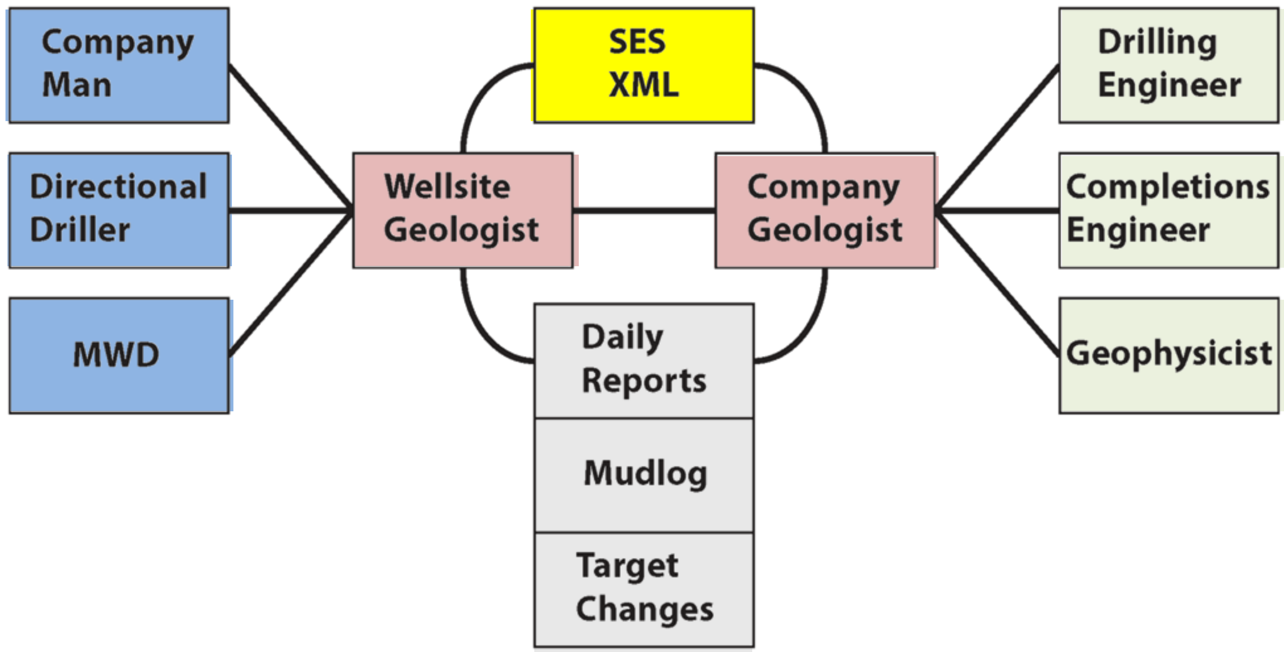
NIOBRARA B GEOSTEERING STRATEGY

- FACIES QUALITY
- FLOW UNIT BOUNDARIES
  - BENTONTIES
  - ORGANIC RICH MUDSTONES
- PSDM STRUCTURE MAPPING
- WHILE DELIEVERING A WELLBORE THAT HAS LOW TORTUOSITY



COMMUNICATION IS CRITICAL

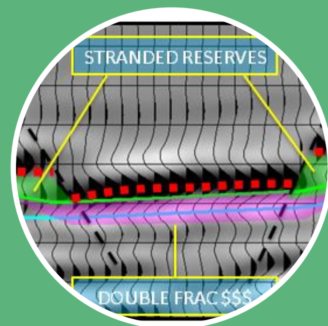
WELLSITE GEOLOGIST SEND AND .XML FOLLOWED WITH A PHONE CALL WHEN LITHOLOGY OR GAMMA CHANGES (DAY OR NIGHT)



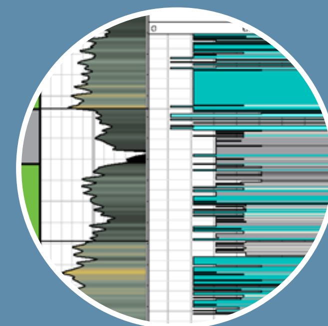
A great philosopher once said "I can fall asleep faster than the rig can sidetrack" - *Mark Odegard*

CONCLUSIONS

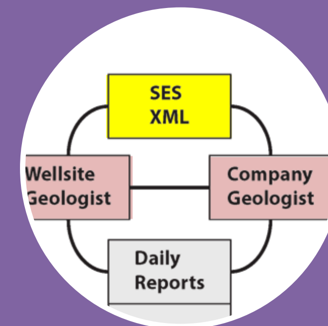
Geosteering Matters Because Facies Matter



Failure to Appreciate Production Barriers Can Strand Reserves



Geosteering Strategies are Zone Dependent



Communication is critical for success

Acknowledgements

CO-AUTHORS

- John Daniels- Staff Geosteerer
- James Huck- Senior Geophysicist
- John Forster- Regional Geologic Manager

SPECIAL THANKS TO;

- Whiting Rock Lab
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  - Lyn Canter, PhD., Senior Geoscience Advisor
  - David Katz, PhD., Petrographer/ Sedimentologist
- Charles Ohlson, Operations Engineer Team Lead
- Mark Williams, SVP Exploration & Development

SEISMIC COURTESY OF GPI/GOK

CROSS SECTIONS COURTESY OF STONER ENGINEERING SOFTWARE