PS Niobrara Core Poster Highlighting Bentonite Distribution and Their Impacts on Proppant Placement*

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Abstract

We exhibit 160' of Niobrara core from the Whiting Razor 25–2514, Weld County, Colorado. The exhibited interval covers the productive Niobrara A chalk, the Niobrara A marl, the productive upper and lower Niobrara B chalk benches and most of the Niobrara B marl. Higher frequency cyclicity and lithologic variation is demonstrated within the chalks due to abundant, thin, black, marly interbeds up to 3” thick; conversely, the A and B marl intervals contain many, thinner, non-amalgamated chalk interbeds. The chalk interbeds within the marls have suppressed UV hydrocarbon fluorescence, probably due to UV quenching from associated elevated asphaltene content. All intervals, including the overlying Sharon Springs Member of the Pierre Shale have bentonites which range from 4” thick in the Sharon Springs to <1/8” thick within the Niobrara Marls. All the bentonites fall below wireline log resolution (with the exception of resistivity imaging), however, we emphasize their distribution with UV photos that highlight each and every bentonite based on bright UV fluorescence. Rock mechanical properties such as Poisson's Ratio and Young's Modulus calculated from dipole sonic logs are largely ignorant of the presence of these abundant, thin, yet very weak, ductile bentonites. Hydraulic Stimulation modeling based on wireline log properties therefore grossly underestimates the mechanical heterogeneity of the Niobrara. Furthermore, the bentonites are too thin and weak to be plugged for static rock mechanics evaluations. To address these limitations, we made extensive usage of the Equotip” “Bambino” micro-rebound hammer to measure closely spaced Unconfined Compressive Strength (UCS) at least every 6” while also covering each and every one of the hundreds of thin bentonites. The UCS from the micro-rebound hammer is compared not only with wireline dipole sonic based parameters, but also with UCS from TerraTek's “Scratch Test”. The Equotip-derived UCS curve, even when running-average-smoothed, demonstrates much greater UCS dynamic range, capturing the very weak bentonite interbeds. Not only do the bentonite (and marl) interbeds divide the chalks into multiple subtle mechanical stratigraphic intervals, but marly intervals with most abundant bentonites impact hydraulic fracture efficiency by limiting proppant placement to the main chalk benches. While fluid-filled fractures have rather extensive vertical propagation throughout the Niobrara A-B-C at peak pump rates, fracture offsets across bentonites and ensuing proppant embedment phenomena eventually render the main marl intervals as barriers to effective stimulation. The impact of bentonites on hydraulic stimulation efficiency was supported by proppant tracer studies in a vertical well stimulation scaled be proportionate to an individual horizontal frac stage. Bentonites changed from our “foes” to our “friends” because their impact on completions supports our multiwall development plans with separate A, B, and C horizontal well targeting.

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ABSTRACT: **We exhibit 80' of Niobrara core from the Whiting Razor 25-2514, Weld County, Colorado. The exhibited interval covers the productive lower Niobrara B chalk bench and the upper portion of the Niobrara B marl. Higher frequency cyclicity and lithologic variation is demonstrated within the chalks due to abundant, thin, black, marly interbeds up to 3" thick; conversely, the A and B marl intervals contain many, thinner, non-amalgamated chalk interbeds. The chalk interbeds within the marls have suppressed UV hydrocarbon fluorescence, probably due to UV quenching from associated elevated asphaltene content.**

All intervals, including the overlying Sharon Springs Member of the Pierre Shale have bentonites which range from 4" thick in the Sharon Springs to <1/8" thick within the Niobrara Marls. All the bentonites fall below wireline log resolution (with the exception of resistivity imaging), however, we emphasize their distribution with UV photos that highlight each and every bentonite based on bright UV fluorescence. Rock mechanical properties such as Poisson's Ratio and Young's Modulus calculated from dipole sonic logs are largely ignorant of the presence of these abundant, thin, yet very weak, ductile bentonites. Hydraulic Stimulation modeling based on wireline log properties therefore grossly underestimates the mechanical heterogeneity of the Niobrara. Furthermore, the bentonites are too thin and weak to be plugged for static rock mechanics evaluations. To address these limitations, we made extensive usage of the Equotip™ "Bambino" micro-rebound hammer to measure closely spaced Unconfined Compressive Strength (UCS) at least every 6" while also covering each and every one of the hundreds of thin bentonites. The UCS from the micro-rebound hammer is compared not only with wireline dipole sonic based parameters, but also with UCS from TerraTek's "Scratch Test". The Equotip-derived UCS curve, even when running-average-smoothed, demonstrates much greater UCS dynamic range, capturing the very weak bentonite interbeds.

Not only do the bentonite (and marl) interbeds divide the chalks into multiple subtle mechanical stratigraphic intervals, but marly intervals with most abundant bentonites impact hydraulic fracture efficiency by limiting proppant placement to the main chalk benches. While fluid-filled fractures have rather extensive vertical propagation throughout the Niobrara A-B-C at peak pump rates, fracture offsets across bentonites and ensuing proppant embedment phenomena eventually render the main marl intervals as barriers to effective stimulation. The impact of bentonites on hydraulic stimulation efficiency was supported by proppant tracer studies in a vertical well stimulation scaled (fluid, proppant, & net stress) to be proportionate to an individual horizontal frac stage. Bentonites changed from our "foes" to our "friends" because their impact on completions supports multiwall development plans with separate A, B, and C horizontal well targeting.

Fig. 1. Whole core example from a Niobrara chalk showing an oil-stained natural fracture (plain light at left and fluorescing under UV light a right) terminating against a 1" bentonite (labeled "E").

Fig. 2. Outcrop example from the Brushy Canyon Formation (Guadalupe National Park, West Texas) showing numerous fractures highlighted in red terminating against a 1 inch bentonite highlighted in yellow.

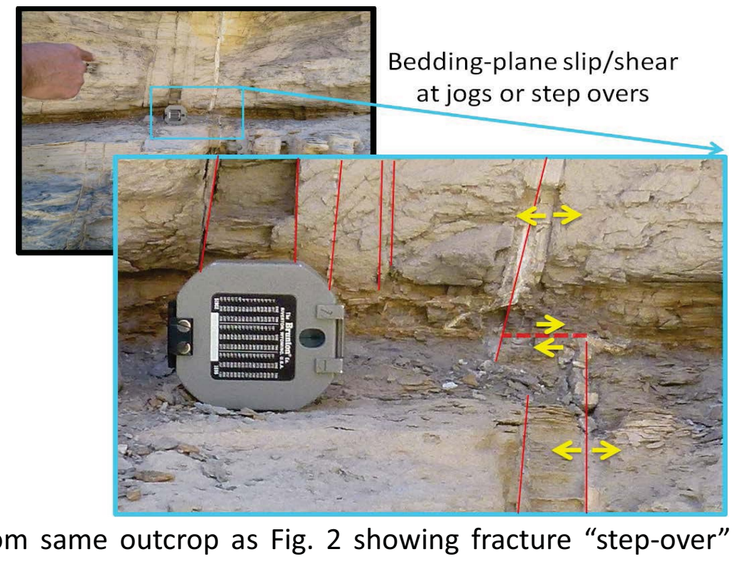
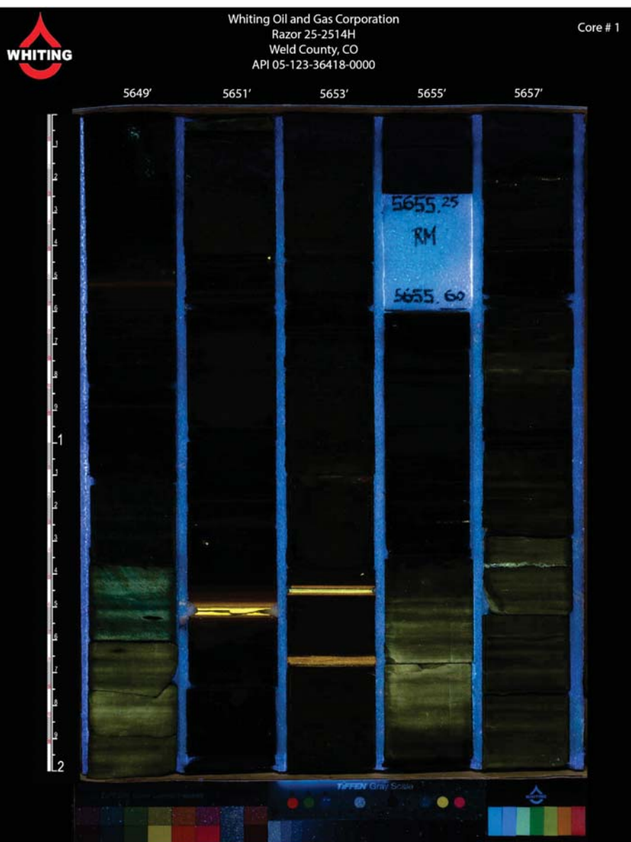
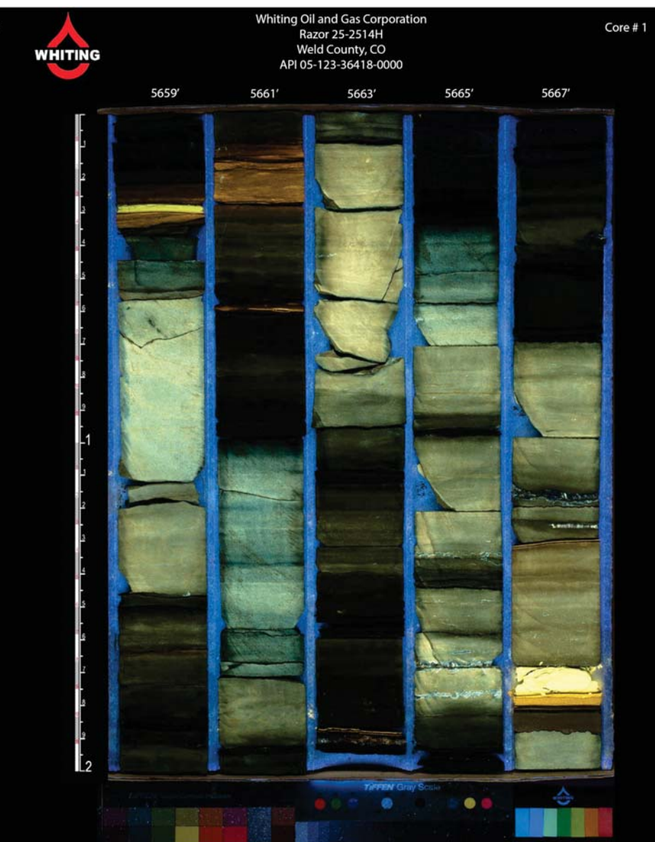
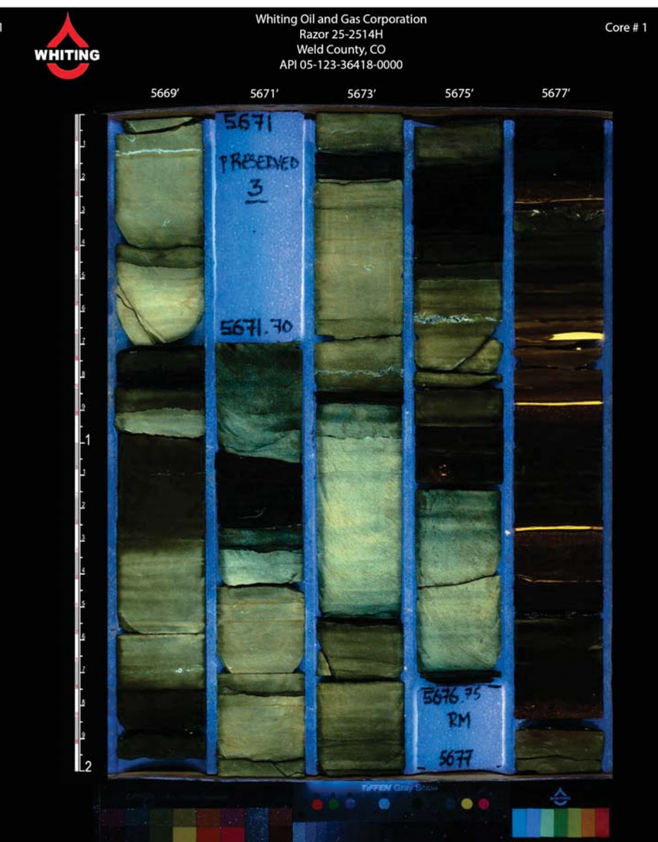
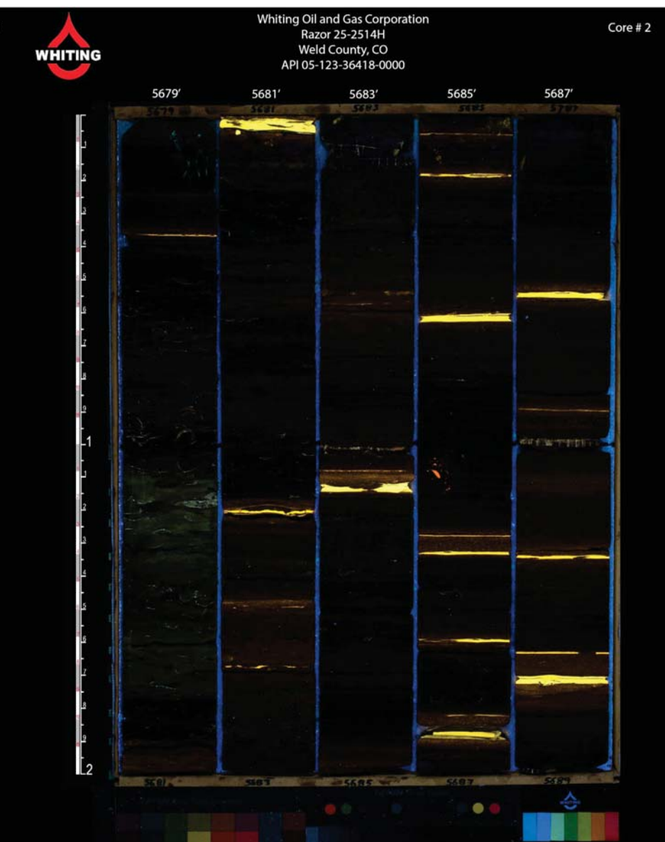


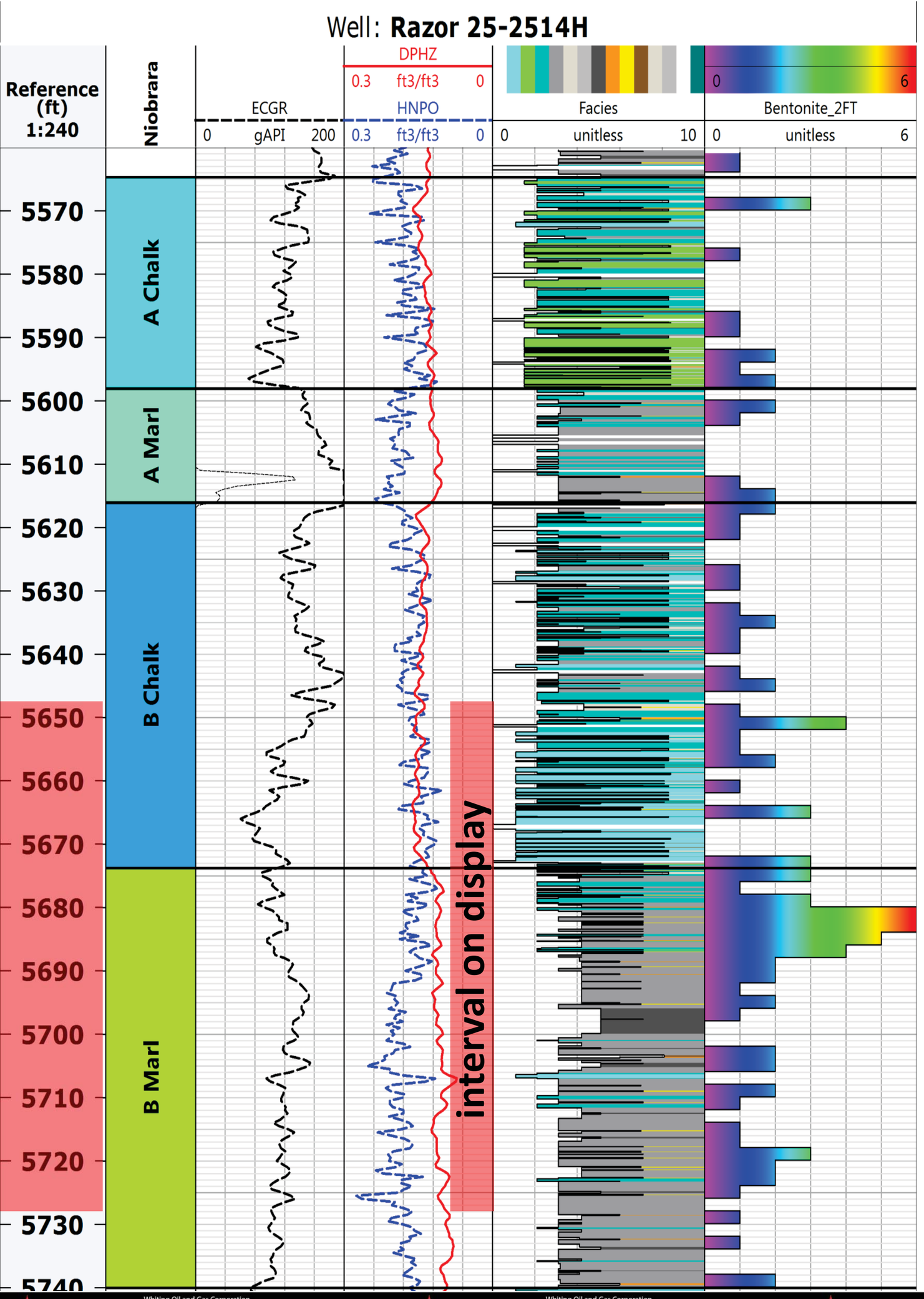
Fig. 3. Close-up from same outcrop as Fig. 2 showing fracture "step-over" across a bentonite. Shearing through a bentonite would simply smear clay and in the case of hydraulic fractures not only be unlikely to remain open against overburden stress, but would almost certainly involve proppant embedment, if proppant could even follow this tortuous path. Similar fracture step-over geometries have been described at intermediate-scale strength contrasts between mechanical interfaces by Helgeson & Aydin (1991) and Cooke &Underwood (2001).







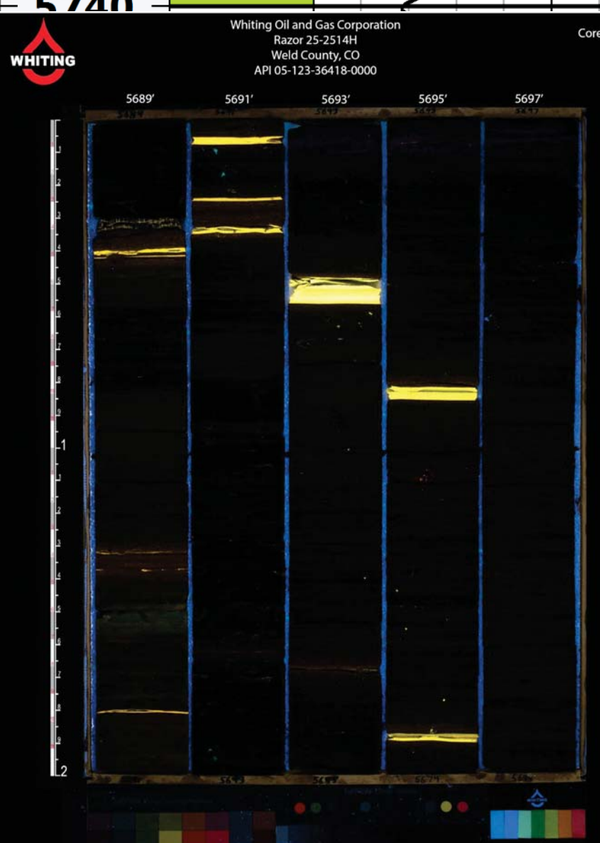


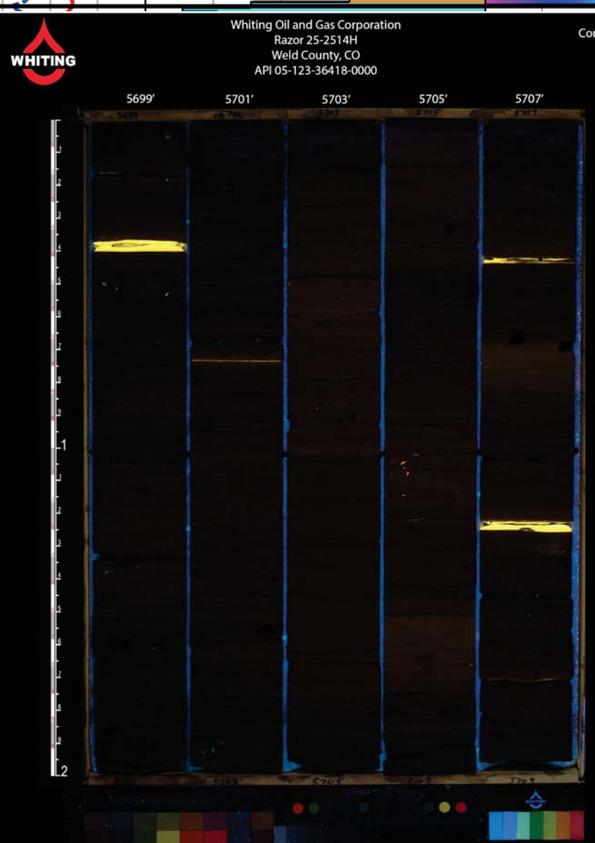


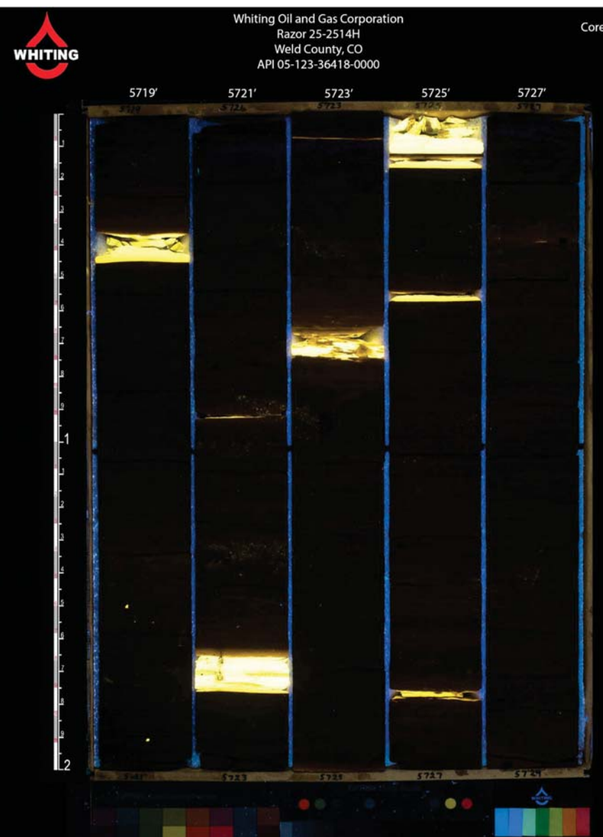
Facies #	DETAILED FACIES
CHALK	
1.1	Burrowed Chalk
1.2	Laminated Chalk
1.3	Burrowed Chalk: with firmgrounds and/or hardgrounds
1.4	Laminated Chalk: with firmgrounds and/or hardgrounds
1.5	Skeletal-Rich Coarse Grained Chalk: coarse grained, skeletal rich
MARLY CHALK	
2.1	Skeletal-Rich Burrowed Marly Chalk:
2.2	Skeletal-Rich Laminated Marly Chalk
2.3	Marly Chalk with Firmground
2.4	Marly Chalk Skeletal Lag
MARL	
3.1	Skeltal-Rich Burrowed Marl
3.2	Laminated Skeletal Marl
3.3	Burrowed Marl with firmground
3.4	Burrowed Marl with harground
4.1	Skeletal Marly Chalk-to-Marl with Inocs & Oysters (forams 'white specs' common)
4.2	Skeletal Marl with Forams "white specs"
MUDSTONE	
5.1	Burrowed Mudstone with organics (intermediate resistivity)
5.2	Laminated Mudstone with organics
8.1	Burrowed Organic rich mudstone (high resistivity)
8.2	Laminated Organich rich Mudstone
BENTONITE	
6	Dispersed Bentonite: significantly reworked through burrowing or currents; most commonly dispersed mudstone lithologies
7	Pure Bentonite: no reworking
7.1	Reworked Bentonite: partially eroded top or strong evidence of erosion by removal of material
MIXED	
4.3	mm-cm scale diffusely laminated organic rich mud and marl (marl may be foram rich or not)
4.4	mm-cm scale sharply laminated organic rich mud and marl
8.3	Interbedded (mm to cm scale) organic rich mudstone with marly chalk
8.4	Interbedded (mm to cm scale) organic rich mudstone with chalk
9	Soft Pebble Lag
10	Hybrid soft pebble lag mixed with marly chalk skeletal lag

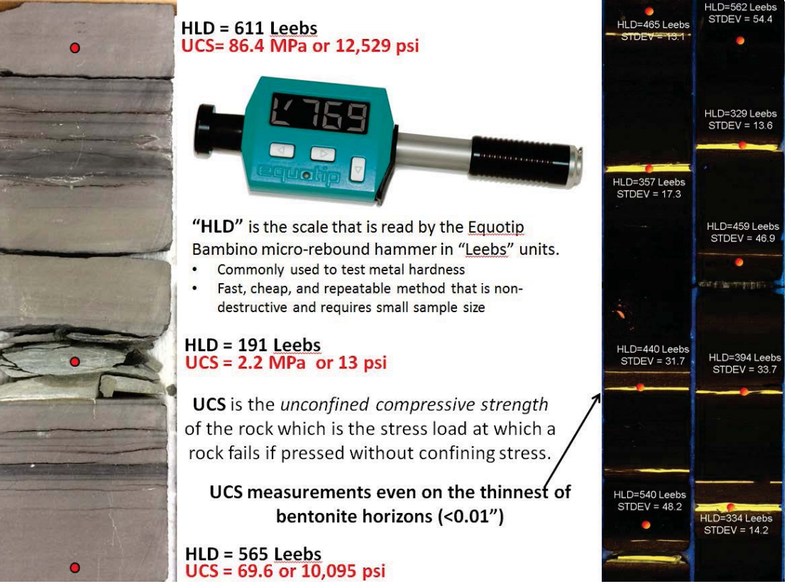
5 GENERALIZED FACIES

- CHALK
- MARLY CHALK
- MARL
- ORGANIC RICH MUDSTONE
- BENTONITE









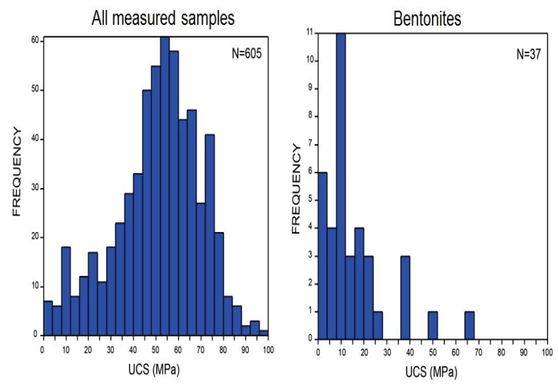
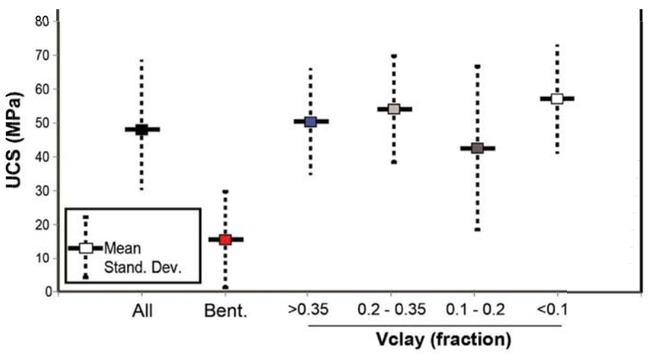


Fig. 5. UCS from Equotip for total Niobrara with histogram at right contrasting distribution for bentonites alone.



Category	Mean UCS (MPa)	Stand. Dev. (MPa)	Number of measurements
All	49.6	19.1	580
Bentonite	15.6	14.2	36
Vclay>0.35	42.6	24.1	51
Vclay 0.2-0.35	54.1	15.7	279
Vclay 0.1-0.2	50.3	15.9	189
Vclay <0.1	57.1	15.9	25

Fig. 6. Summary of UCS by Vclay for all Niobrara. Note limited separation among Niobrara chalk and marl measurements as compared to significant separation toward much lower UCS for the bentonite measurements. This highlights why rock mechanics and hydraulic fracture models across the Niobrara overemphasize fracture height growth and connectivity unless the impact of sub-log resolution bentonites is considered. the results of a standard frac job.

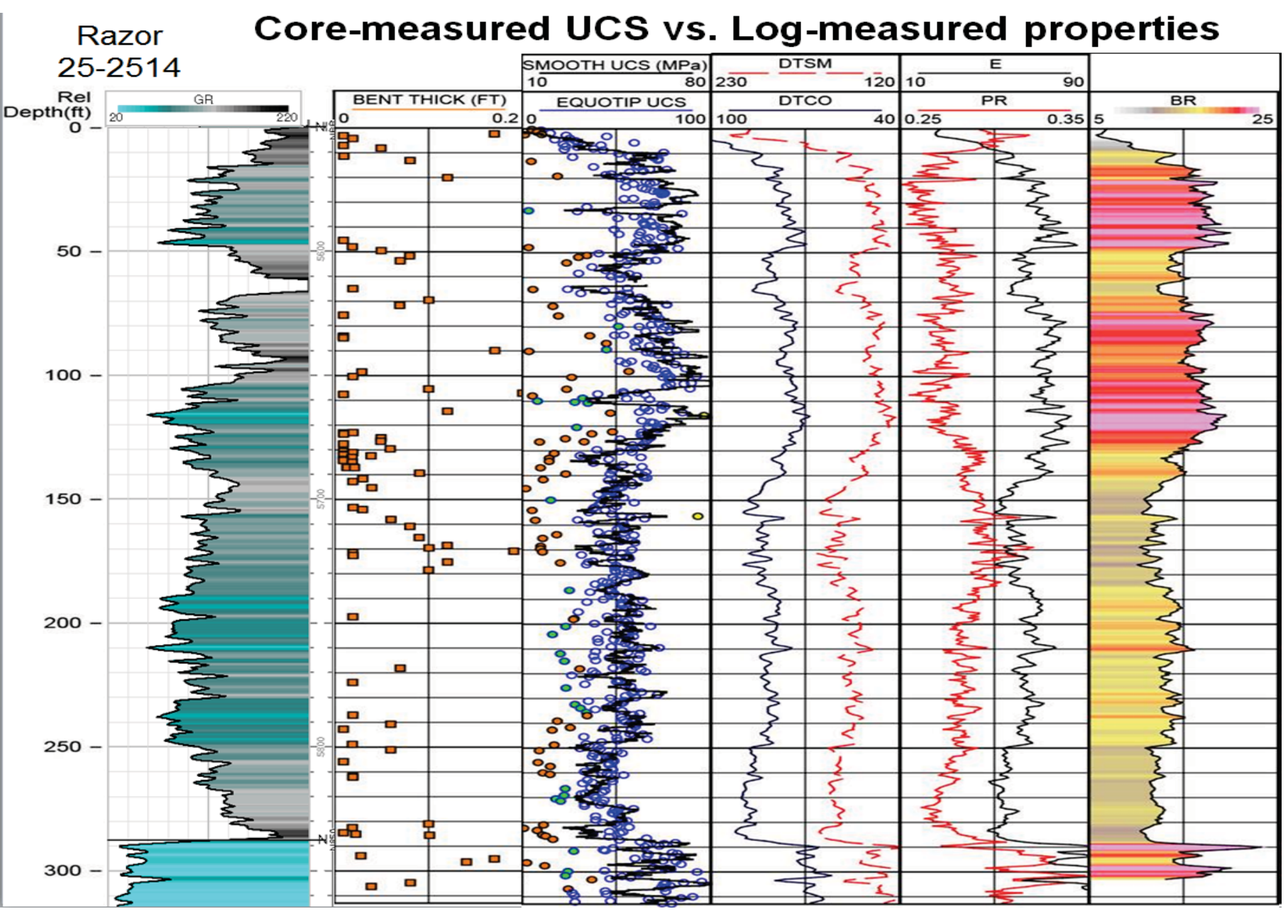
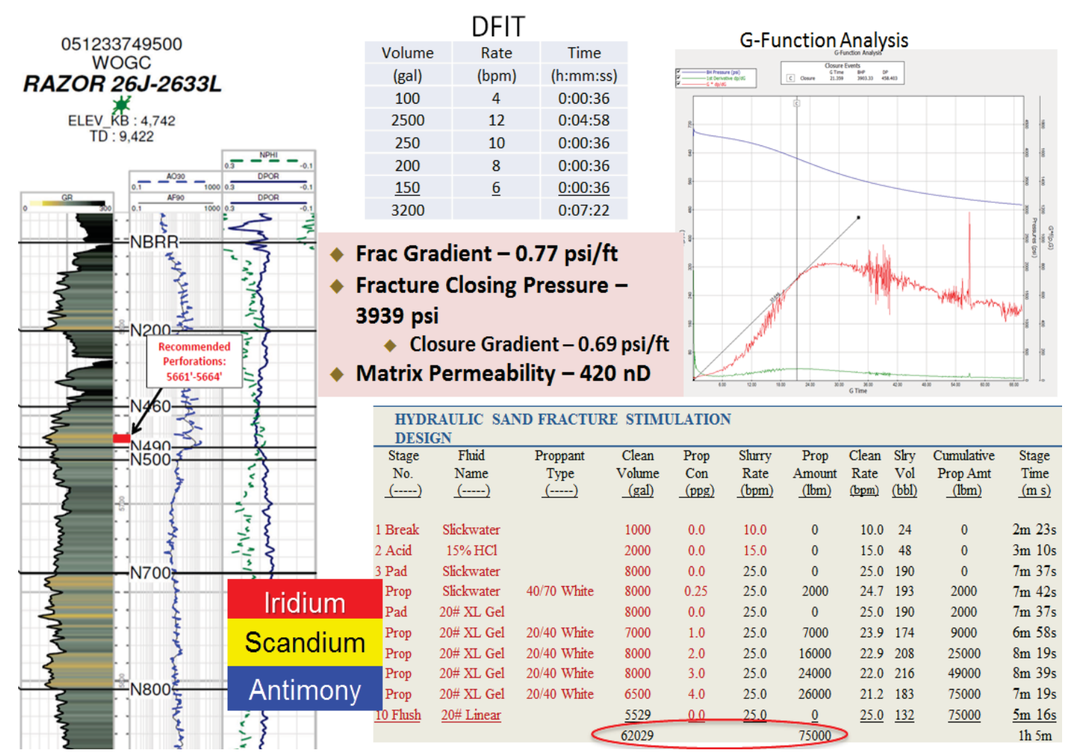


Fig. 7. Track 3 shows discrete Equotip UCS values in blue and orange circles. The orange circles correspond to thin bentonite UCS values--note they are MUCH lower than the overall UCS population; they are also lower than the smoothed UCS curve designed to mimic dipole sonic log resolution of approximately 2 feet. Track 4 shows shear and compressional velocities, Track 5 shows Young's Modulus and Poisson's Ratio, all derived from the wireline dipole sonic. Track 6 is "brittleness index" (E/PR). Note that none of the wireline-derived rock properties has resolution or dynamic range to capture the impact of the low UCS thin bentonites.



Volume (gal)	Rate (bpm)	Time (h:mm:ss)
100	4	0:00:36
2500	12	0:04:58
250	10	0:00:36
200	8	0:00:36
150	6	0:00:36
3200		0:07:22

HYDRAULIC SAND FRACTURE STIMULATION DESIGN

Stage No. (-----)	Fluid Name (-----)	Proppant Type (-----)	Clean Volume (gal)	Prop Con (ppg)	Slurry Rate (bpm)	Prop Amount (lbm)	Clean Rate (bpm)	Slry Vol (bbl)	Cumulative Prop Amt (lbm)	Stage Time (m s)
1 Break	Slickwater		1000	0.0	10.0	0	10.0	24	0	2m 23s
2 Acid	15% HCl		2000	0.0	15.0	0	15.0	48	0	3m 10s
3 Pad	Slickwater		8000	0.0	25.0	0	25.0	190	0	7m 37s
Prop	Slickwater	40/70 White	8000	0.25	25.0	2000	24.7	193	2000	7m 42s
Pad	20# XL Gel		8000	0.0	25.0	0	25.0	190	2000	7m 37s
Prop	20# XL Gel	20/40 White	7000	1.0	25.0	7000	23.9	174	9000	6m 58s
Prop	20# XL Gel	20/40 White	8000	2.0	25.0	16000	22.9	208	25000	8m 19s
Prop	20# XL Gel	20/40 White	8000	3.0	25.0	24000	22.0	216	49000	8m 39s
Prop	20# XL Gel	20/40 White	6500	4.0	25.0	26000	21.2	183	75000	7m 19s
10 Flush	20# Linear		5529	0.0	25.0	0	25.0	132	75000	5m 16s
			62029			75000				1h 5m

Fig. 8. Stages 4-9 of a limited-entry fracture stimulation of the B chalk in a vertical well were tagged with Iridium, Scandium, and Antimony radioactive tracers. The stimulation was scaled to be approximately equivalent to a horizontal single entry stage. job.

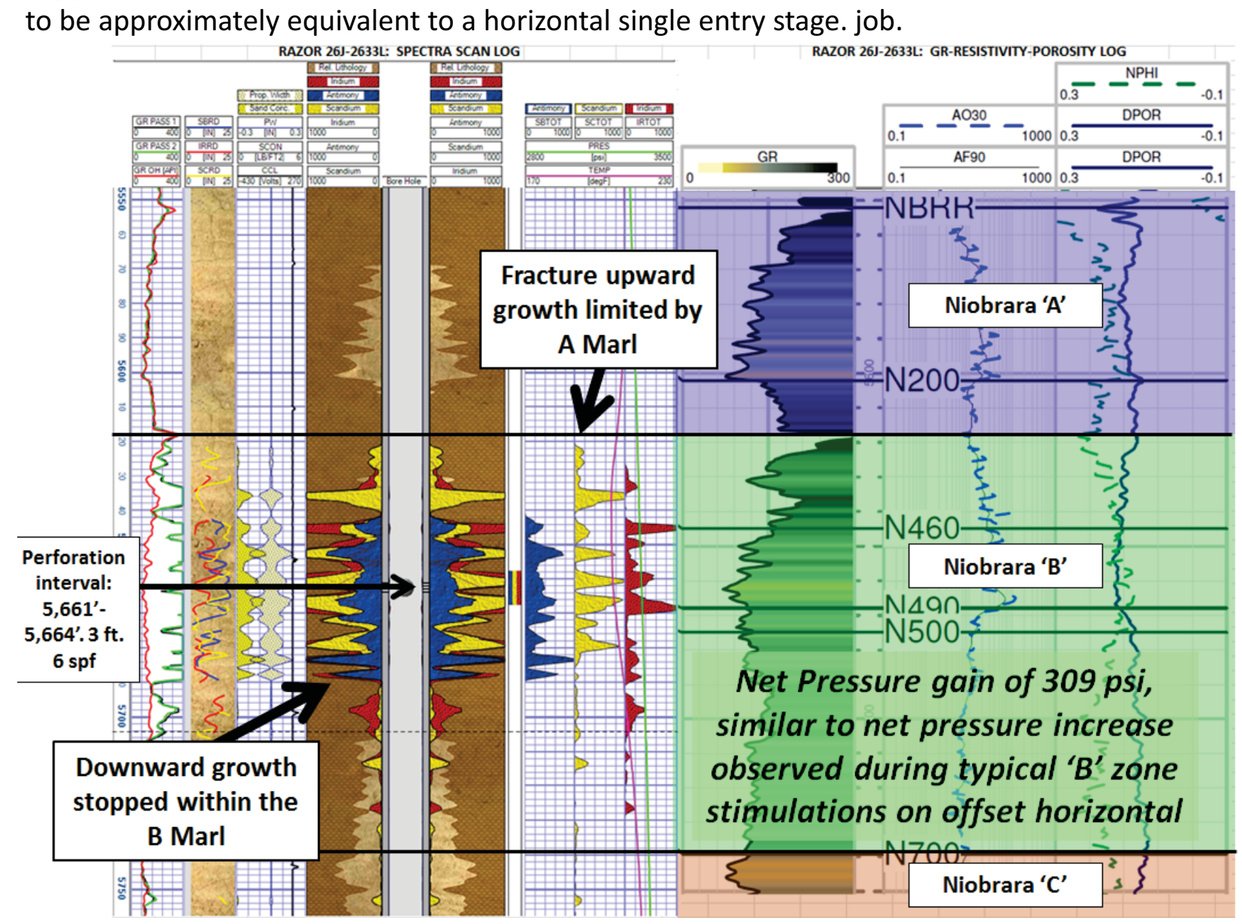


Fig. 9. Results of tagged vertical fracture stimulation showing that neither the Iridium (red), Scandium (yellow), nor Antimony (blue) proppant extended beyond the bentonite-rich marl intervals bounding the B chalk. Propped fractures do not bust out of zone and instead stay confined to the 'B'. The net pressure gain during the stimulation was very similar to that experienced during horizontal stages, another indicator that we were successful in replicating the results of a standard frac job.

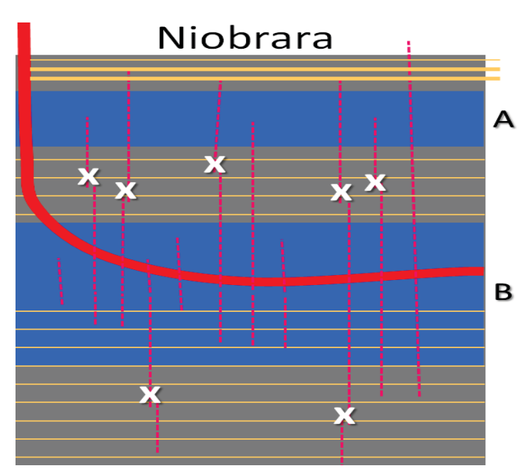


Fig. 10 Sketch depicting contrast in vertical hydraulic fracture height (red dashed lines) at peak pump rate vs. hypothesized spots/zones of fracture annealment at any one of the many bentonites bounding the Niobrara B chalk interval. The annealment from bentonite shear with or without proppant embedment at step-over zones results in eventual isolation of the B Chalk interval from the A Chalk interval.

Conclusions: **The Niobrara Formation has abundant very thin bentonites. All individual bentonites fall below dipole sonic and gamma ray wireline log resolution; consequently, we captured their distribution from core observation. Rock mechanical properties such as Poisson's Ratio and Young's Modulus calculated from dipole sonic logs are largely ignorant of the presence of these abundant, thin, yet very weak, ductile bentonites. Hydraulic stimulation modeling based on wireline log properties, therefore, grossly underestimates the mechanical heterogeneity of the Niobrara. To address these limitations, we made extensive usage of the Equotip™ micro-rebound hammer to measure Unconfined Compressive Strength (UCS) of each and every one of the hundreds of thin bentonites.**

A scaled and radioactive proppant traced fracture stimulation within a vertical well demonstrated that the A and B marly intervals with most abundant bentonites impact hydraulic fracture efficiency by limiting proppant placement to the intervening B chalk bench. While fluid-filled fractures have rather extensive vertical propagation throughout the Niobrara A-B-C *at peak pump rates*, fracture offsets across bentonites and ensuing proppant embedment phenomena eventually render the main marl intervals as barriers to effective stimulation.

WHITING