Lithologic controls on geomechanical properties of the Mancos Shale: eastern San Juan Basin, NM

SAND2014-16282PE

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Sandia National Laboratories

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH UNIVERSITY

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Outline

- Purpose/Importance of Research
- Study Area & Geologic Overview
- Methods
- Results & Discussion
- Conclusions
- Suggestions for Future Work
- Acknowledgements

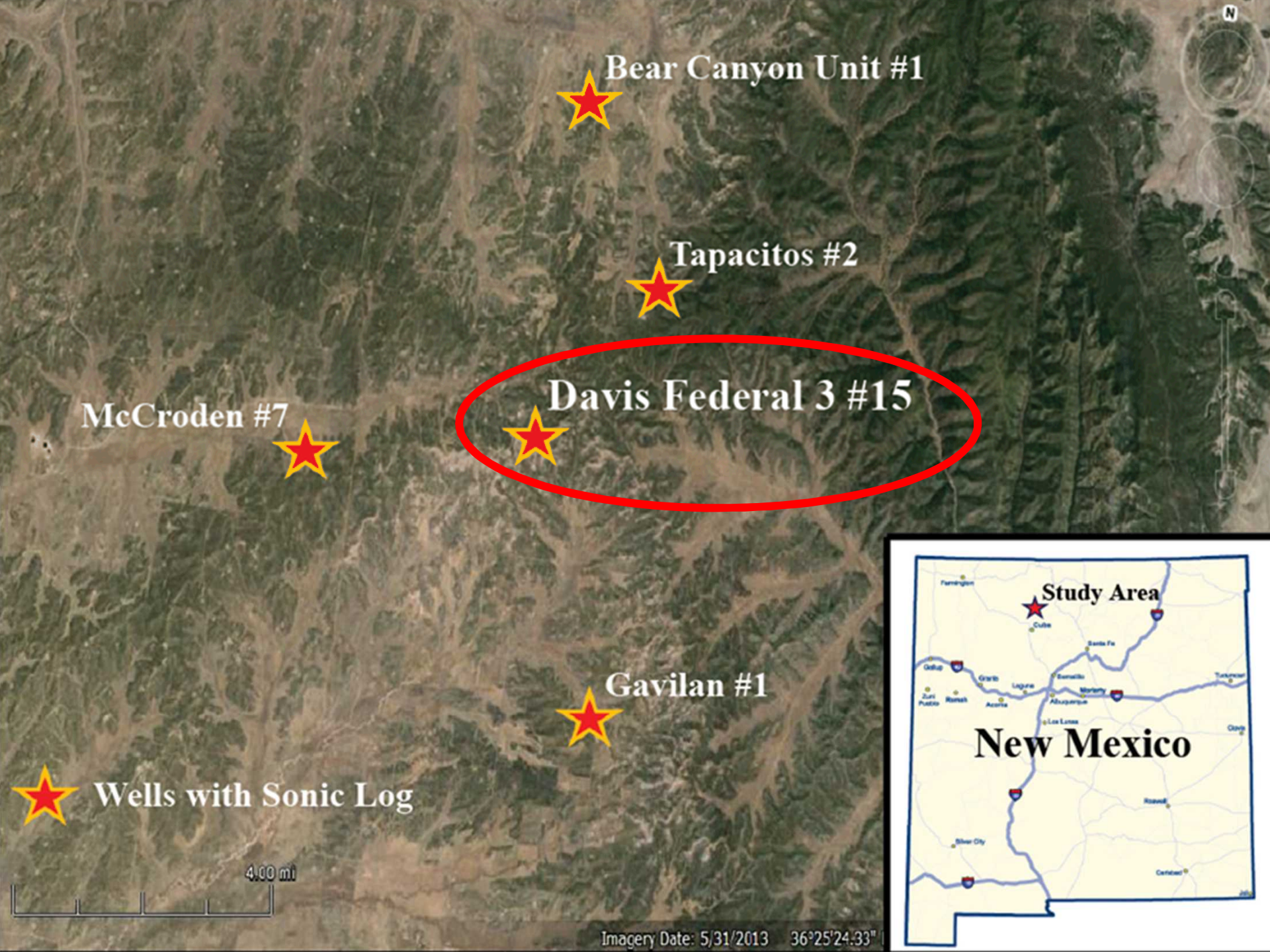
Purpose of Research

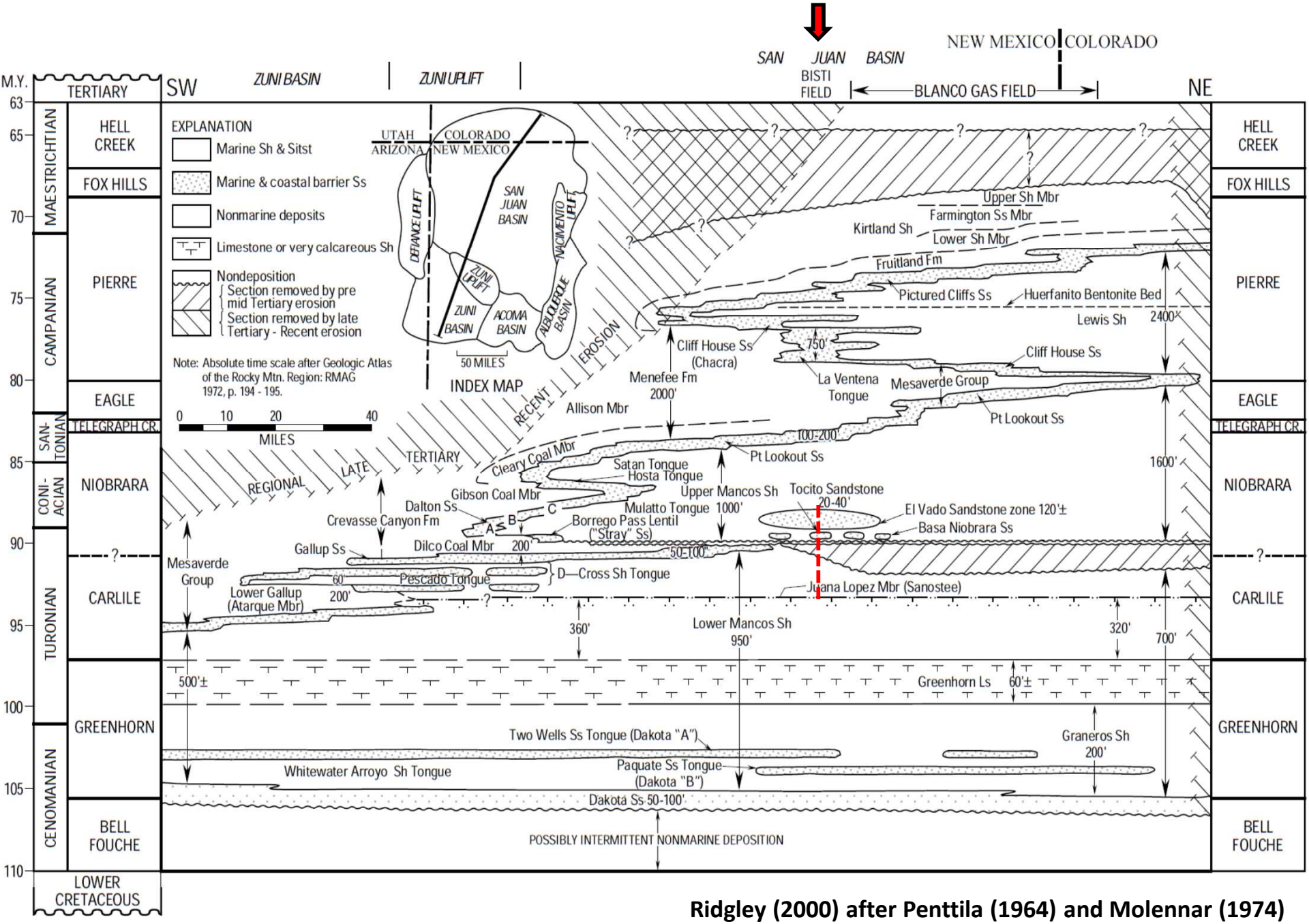
- Determine if shale facies
  - Have distinct velocity characteristics
  - Can be identified using sonic log data
- Determine the main controls on the velocity

Importance of Research

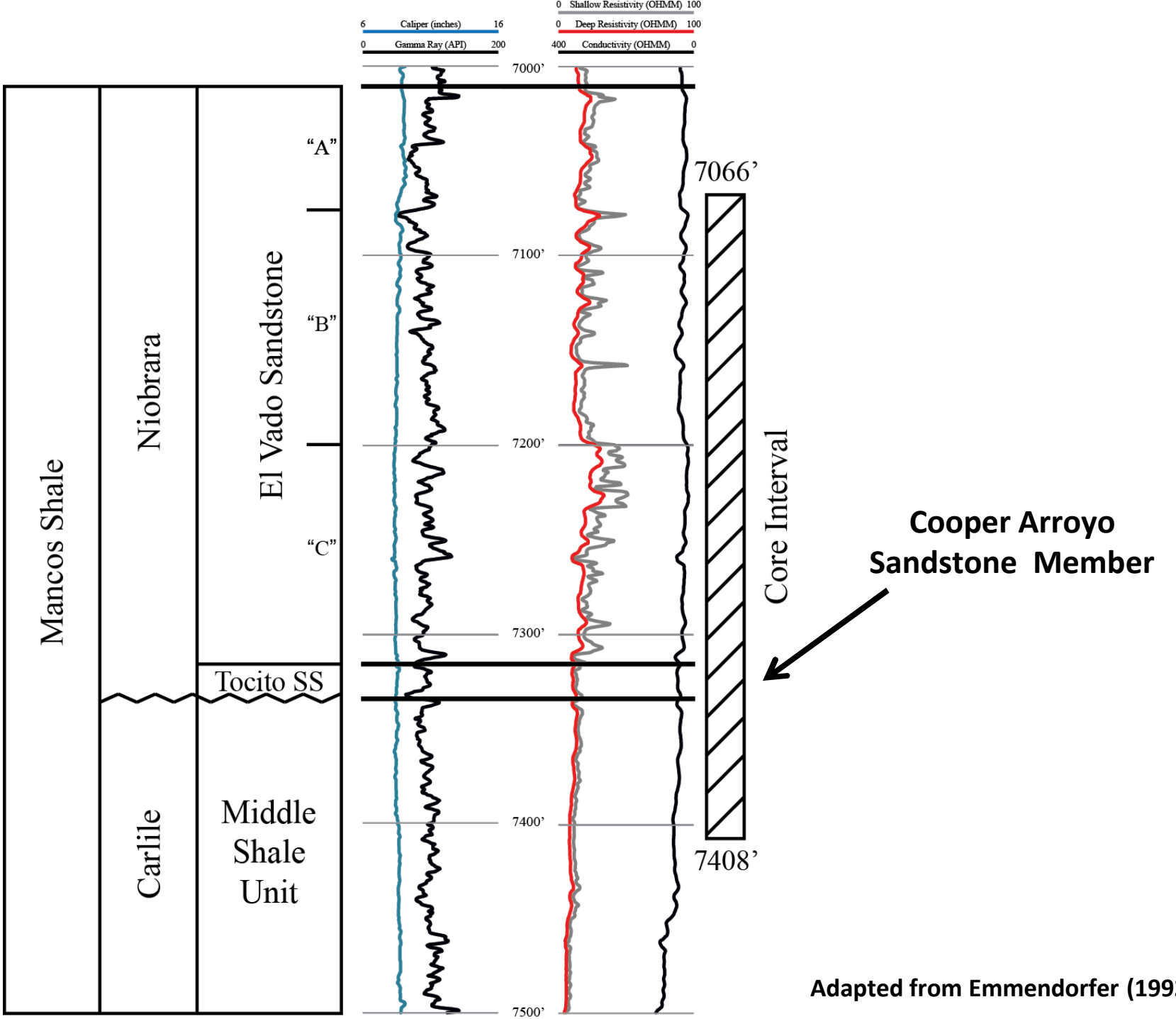
- Improve interpretation of shale heterogeneities for resource extraction
  - Hydraulic fracturing
  - Caprock integrity and mitigation

STUDY AREA & GEOLOGIC OVERVIEW


Bear Canyon Unit #1
Tapacitos #2
Davis Federal 3 #15
McCroden #7
Gavilan #1
Wells with Sonic Log
4.00 mi
Imagery Date: 5/31/2013 36°25'24.33"
Study Area
New Mexico



Ridgley (2000) after Penttila (1964) and Molennar (1974)

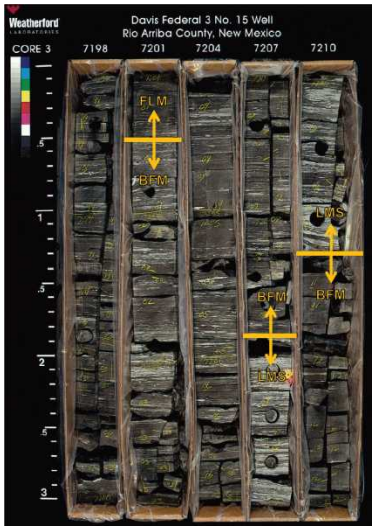


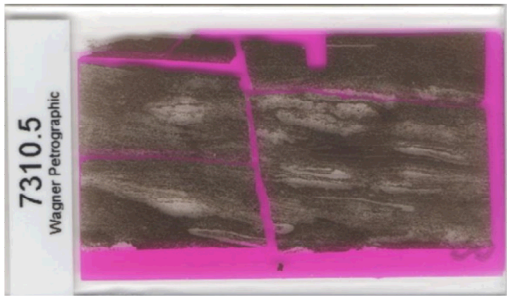
Adapted from Emmendorfer (1992)

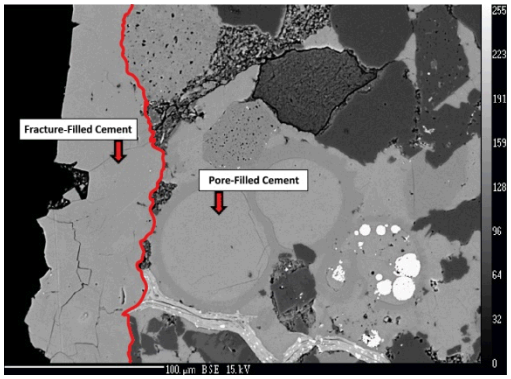
METHODS

Methods

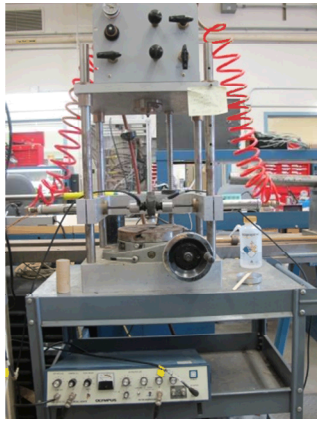
- Core-Related
  - Conventional Core
  - Petrography
  - Stable Isotopes
  - Electron Microprobe

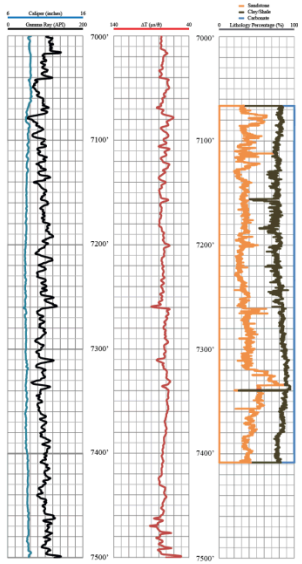






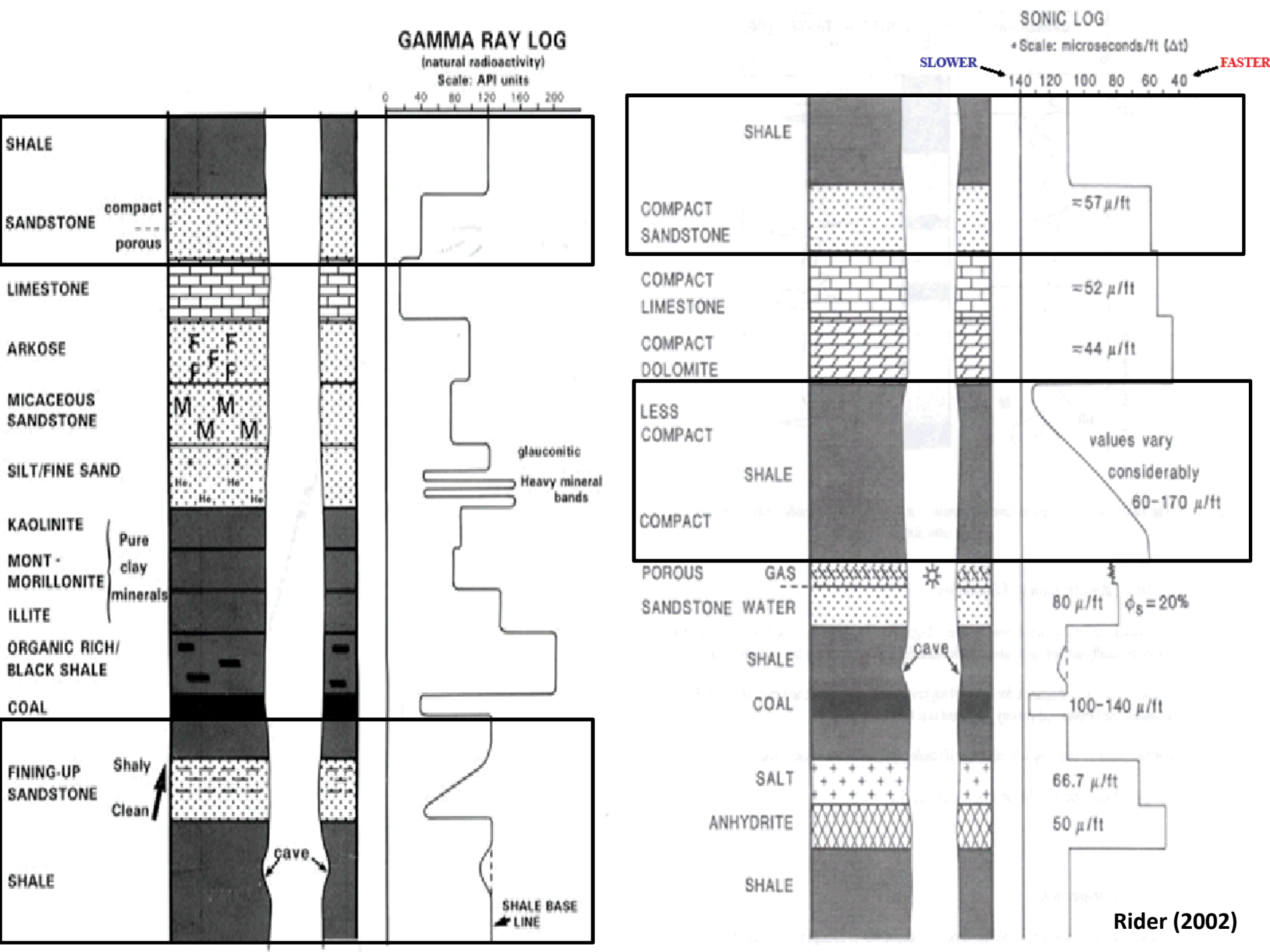
- Log-Related
  - Electric Log Interpretation
    → Sonic, Gamma Ray, & Caliper Logs
  - Velocity Bench
    → Precision Measurements





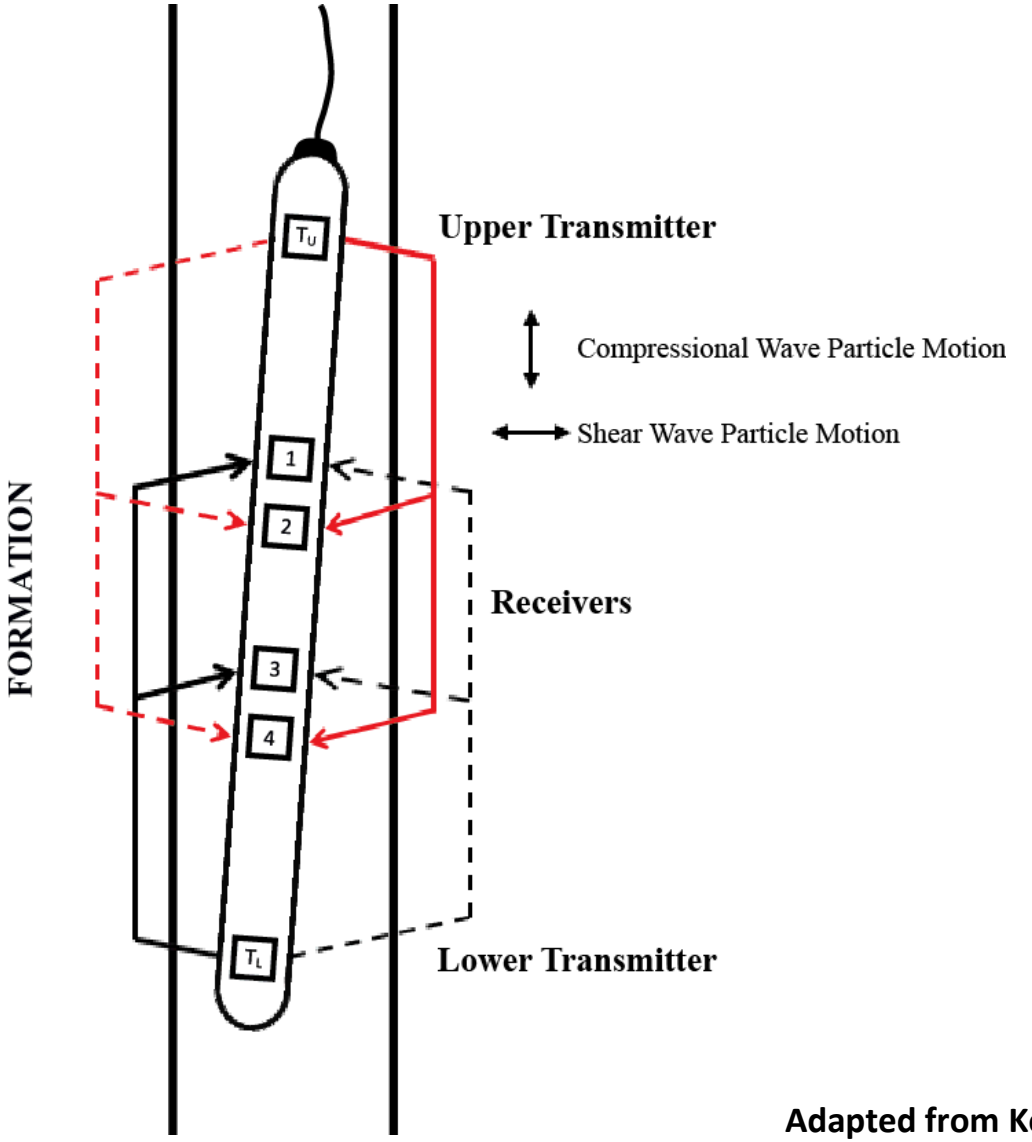
Electric Logs

1) Gamma Ray
   - Measures natural gamma radioactivity of a formation (API)
     → Shales have higher gamma signatures than sandstones
2) Sonic/Acoustic Velocity
   - Measures travel time through a formation (μs/ft)
     → Shales have longer travel times than sandstones
3) Caliper
   - Measures the size of the borehole
     → enlarged borehole can affect electric log measurements


GAMMA RAY LOG
(natural radioactivity)
Scale: API units
0 40 80 120 160 200
SHALE
SANDSTONE
compact
porous
LIMESTONE
ARKOSE
MICACEOUS SANDSTONE
SILT/FINE SAND
KAOLINITE
MONT-MORILLONITE
ILLITE
Pure clay minerals
ORGANIC RICH/ BLACK SHALE
COAL
FINING-UP SANDSTONE
Shaly
Clean
SHALE
cave
glauconitic
Heavy mineral bands
SHALE BASE LINE
SONIC LOG
Scale: microseconds/ft (Δt)
SLOWER
FASTER
140 120 100 80 60 40
SHALE
COMPACT SANDSTONE
=57 μ/ft
COMPACT LIMESTONE
=52 μ/ft
COMPACT DOLOMITE
=44 μ/ft
LESS COMPACT SHALE
COMPACT
values vary considerably 60-170 μ/ft
POROUS GAS
SANDSTONE WATER
80 μ/ft
ϕ_S=20%
SHALE
cave
COAL
100-140 μ/ft
SALT
66.7 μ/ft
ANHYDRITE
50 μ/ft
SHALE

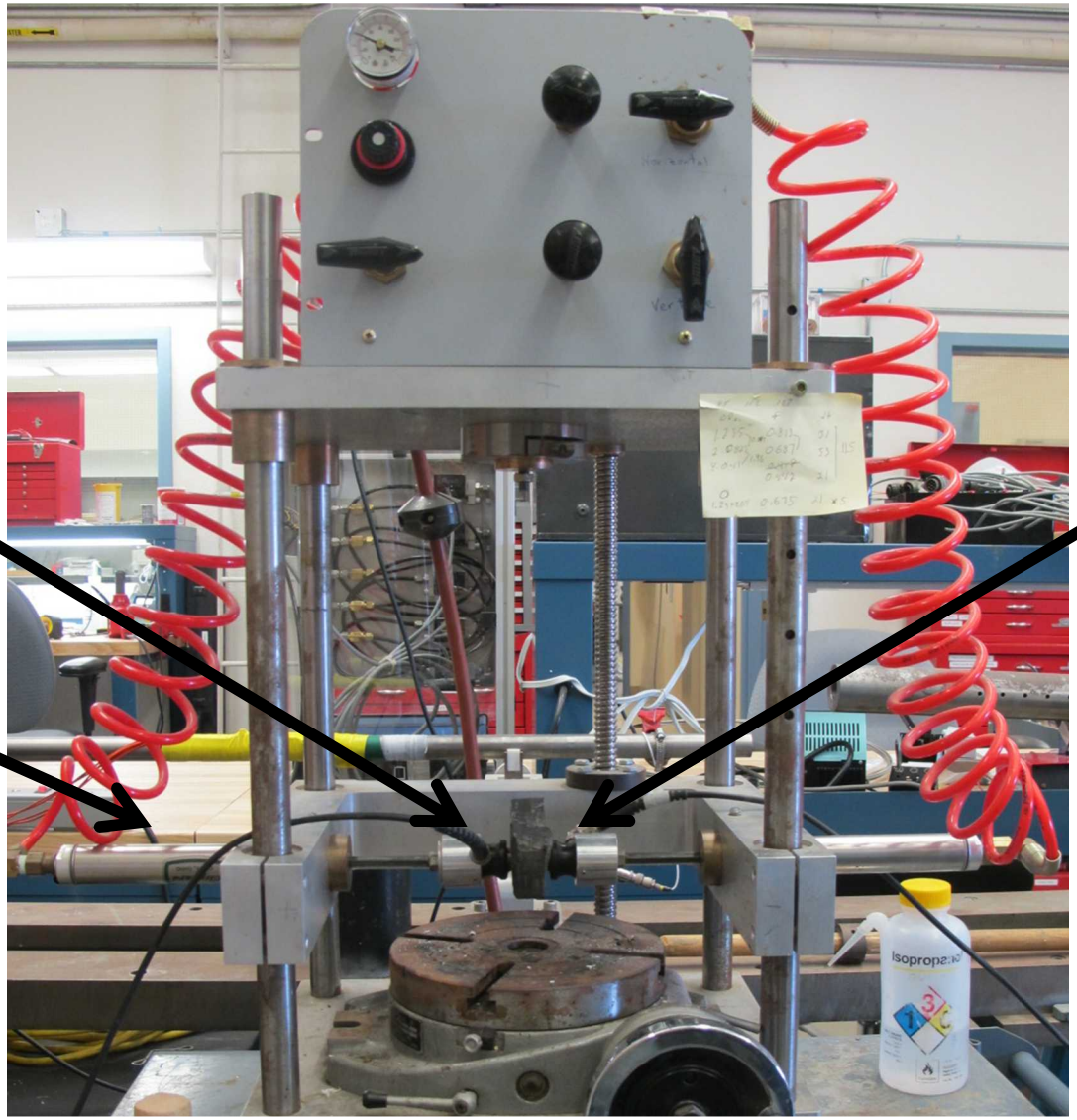
Rider (2002)

How Does the Sonic Log Work?



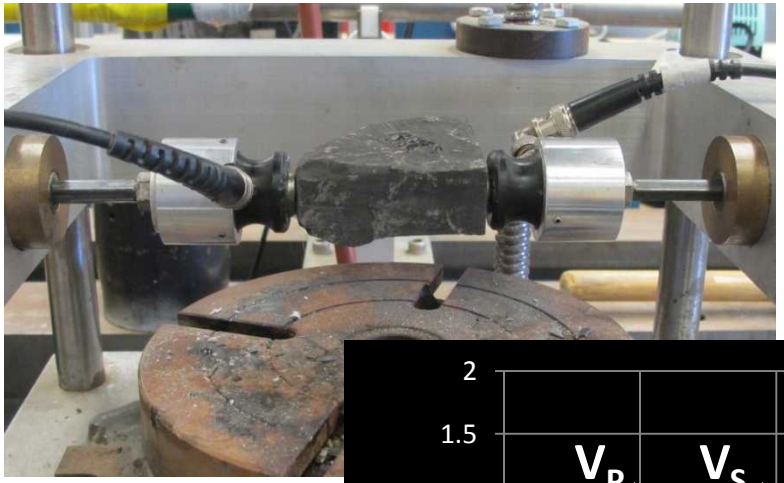
Adapted from Kokesh et al. (1965)

Velocity Bench

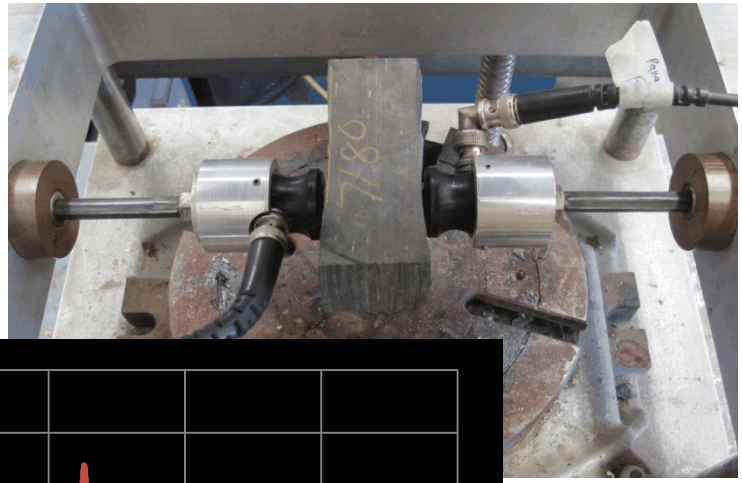


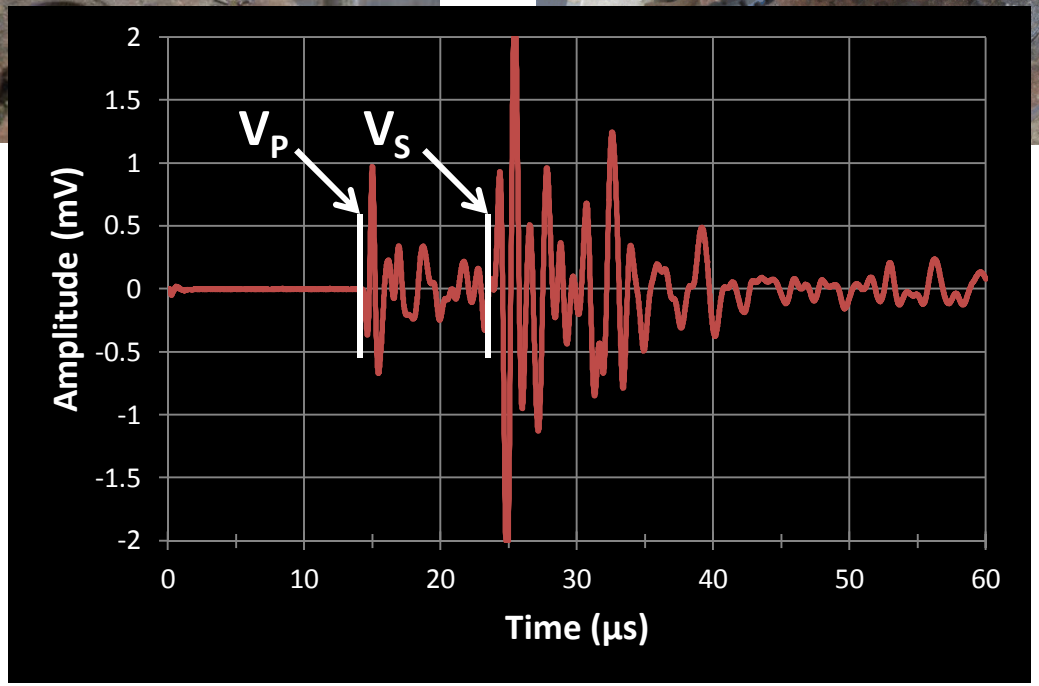
Velocity Bench

Parallel to Bedding

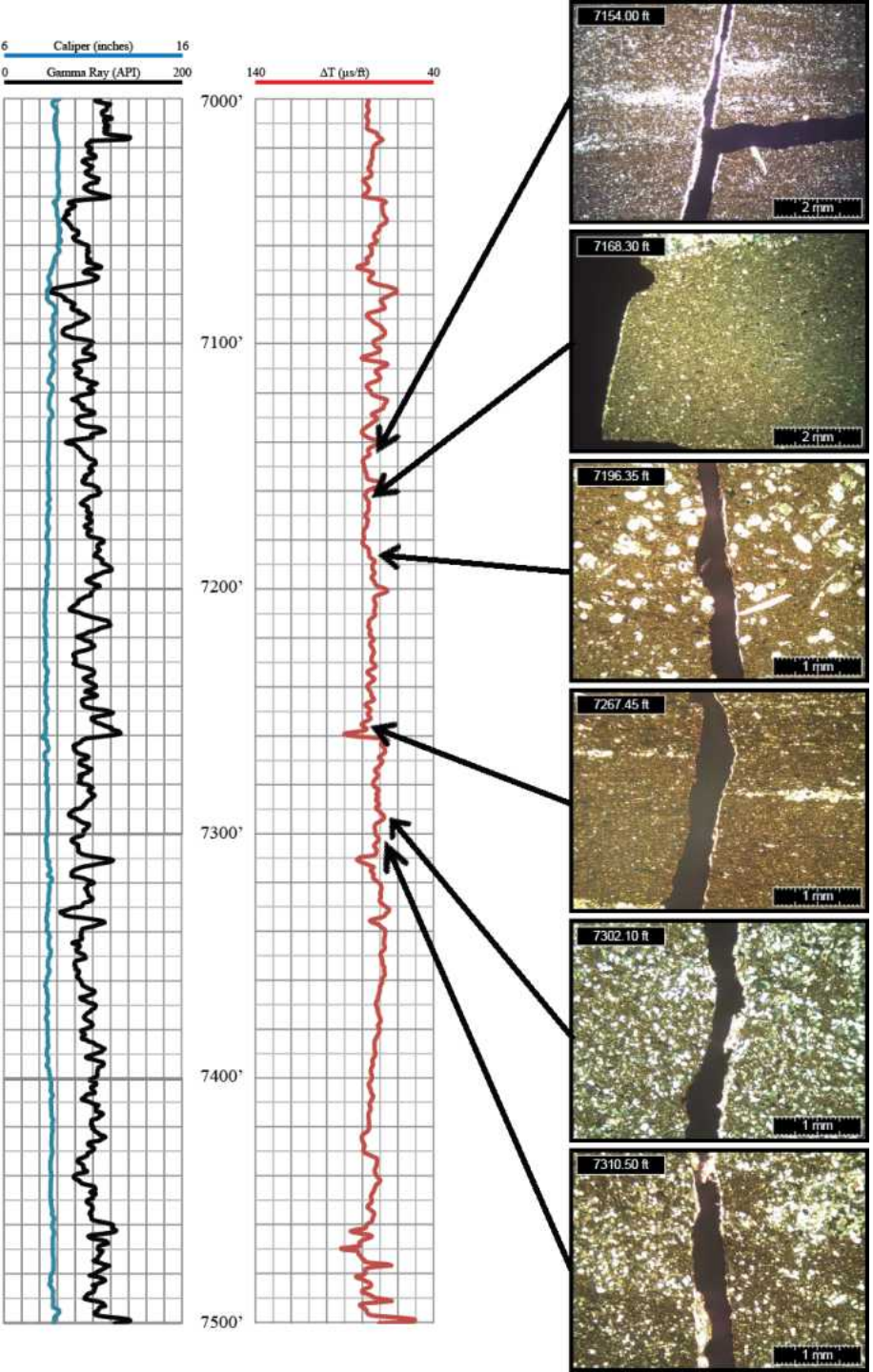


Perpendicular to Bedding





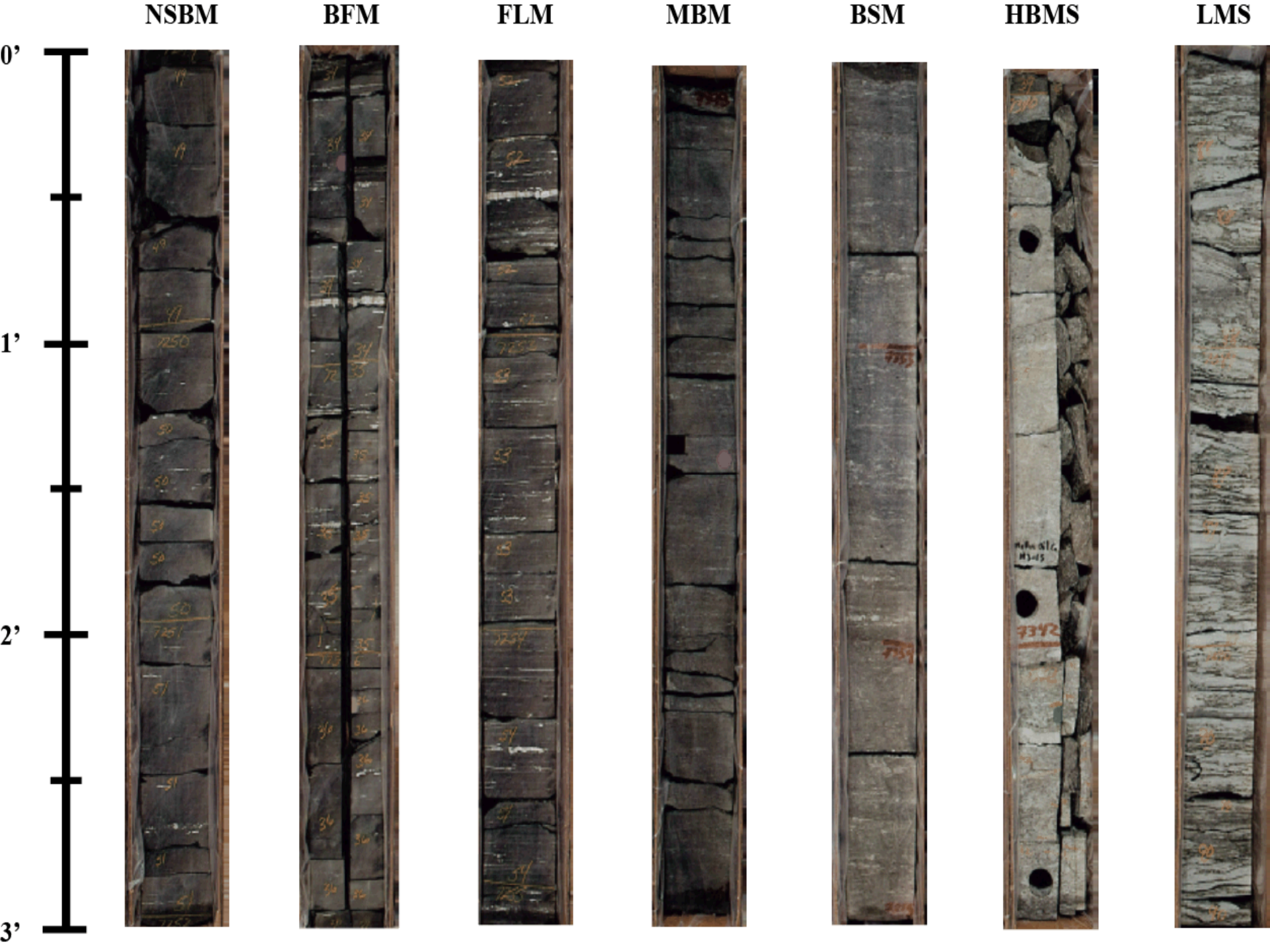
RESULTS & DISCUSSION



- Natural Fractures
  - Is there any relation to lithology?
  - Can they be identified using the sonic log?
  - Can something about their origin be determined?

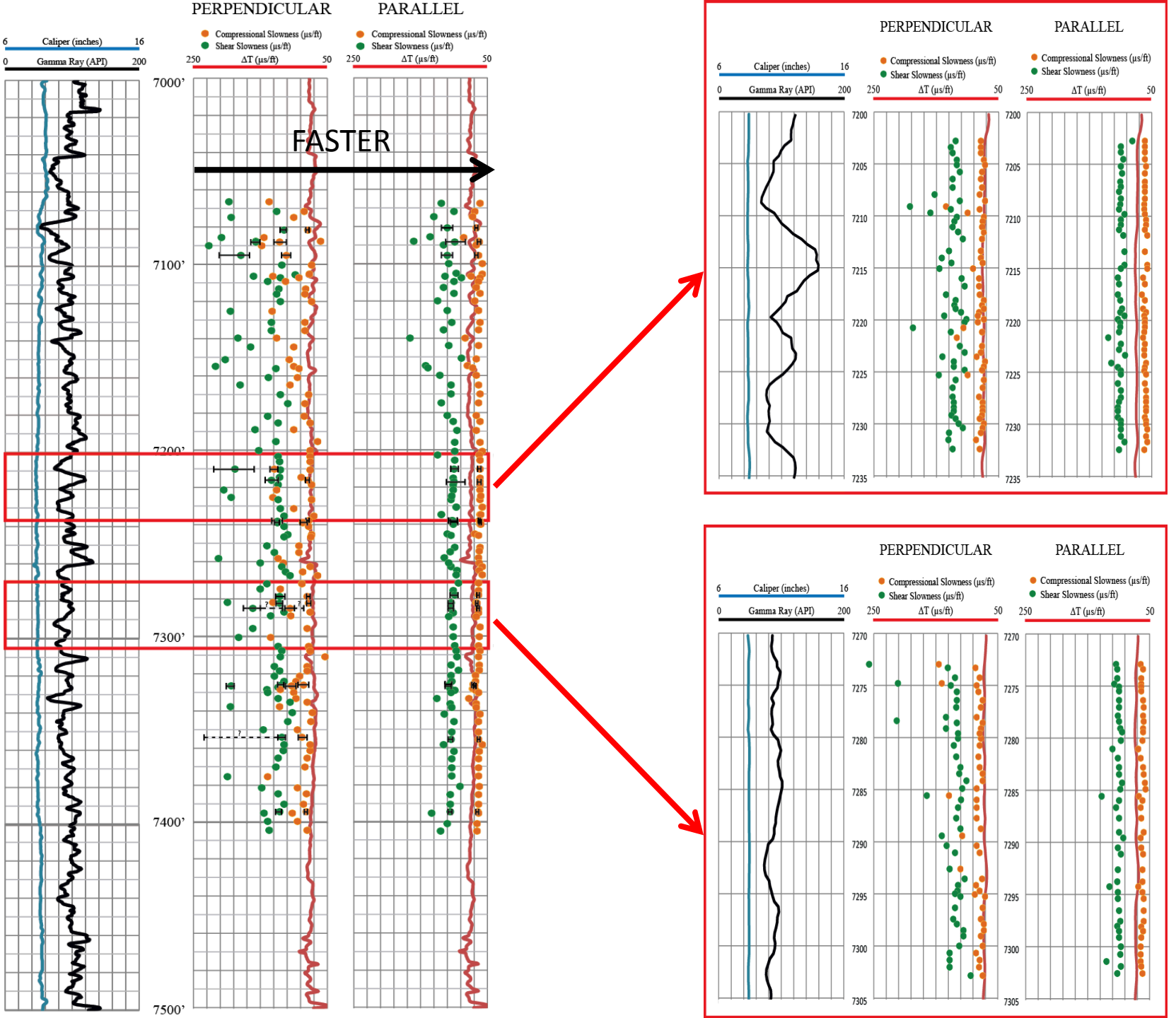
Lithofacies Identification

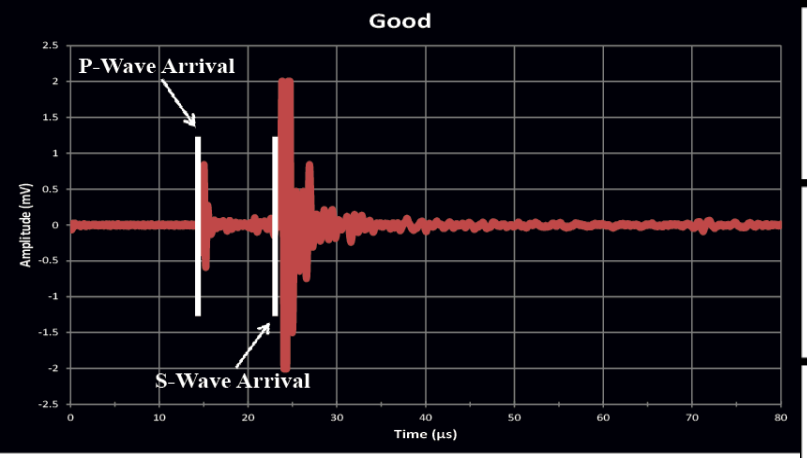
- Seven detailed facies identified in the core
  1) Laminated, Muddy Sandstone (LMS)
  2) Highly Bioturbated, Muddy Sandstone (HBMS)
  3) Bioturbated, Sandy Mudstone (BSM)
  4) Nonfossiliferous, Strongly Bioturbated Mudstone (NSBM)
  5) Moderately Bioturbated Mudstone (MBM)
  6) Fossiliferous, Laminated Mudstone (FLM)
  7) Bioturbated, Fossiliferous Mudstone (BFM)

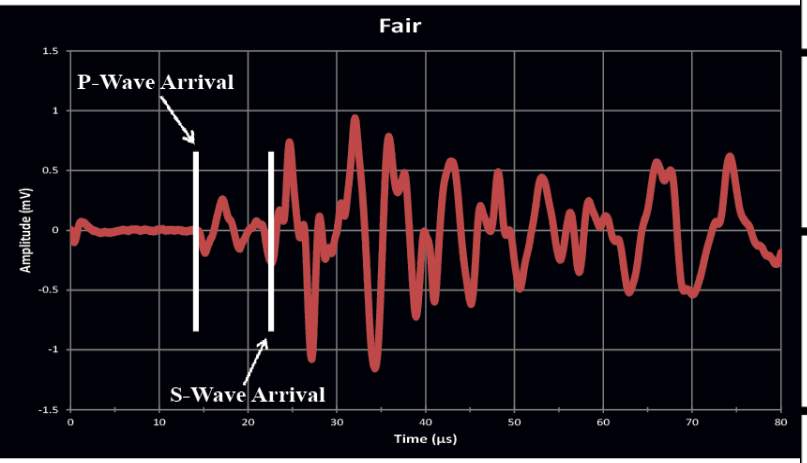

NSBM
BFM
FLM
MBM
BSM
HBMS
LMS
0’
1’
2’
3’

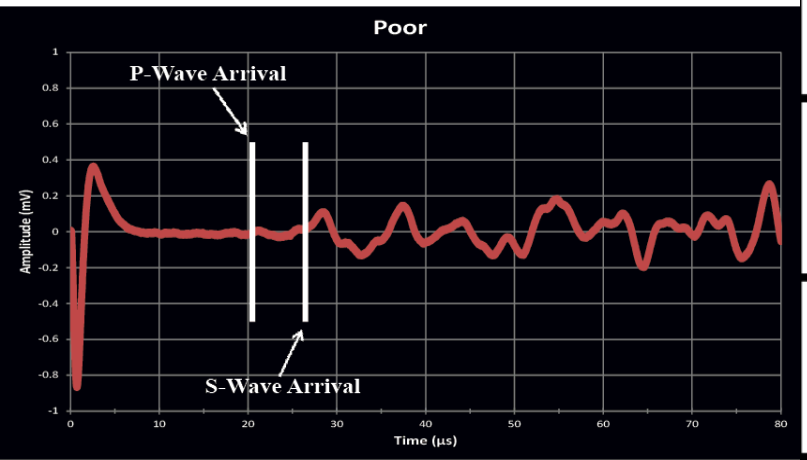
Comparing Velocity Bench to Sonic Log

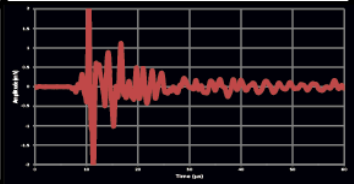
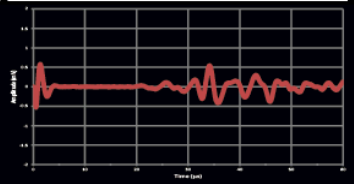
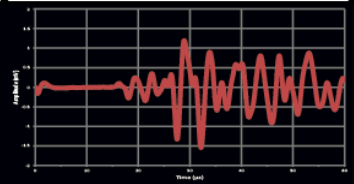
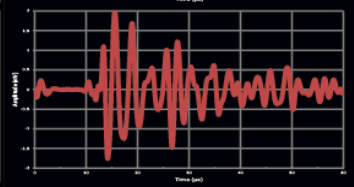
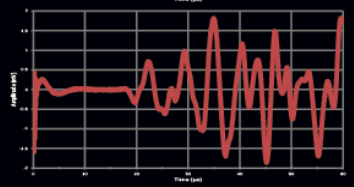
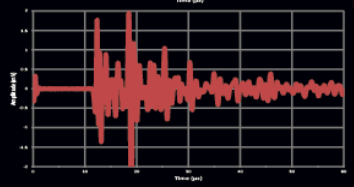
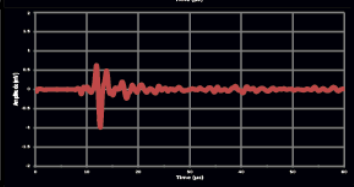
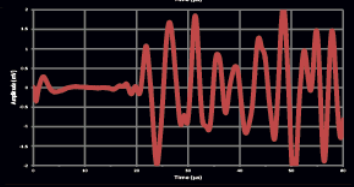
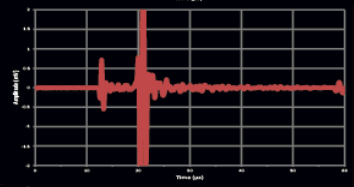
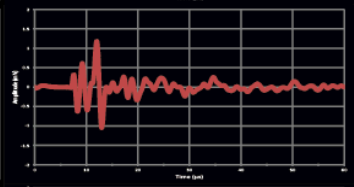
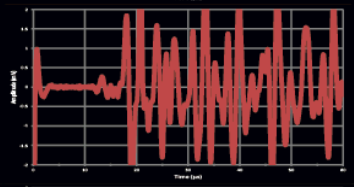
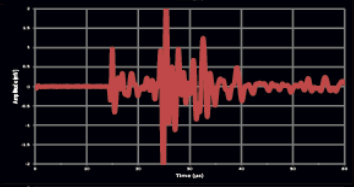
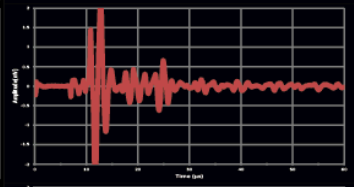
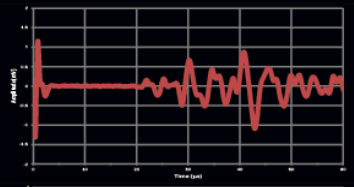
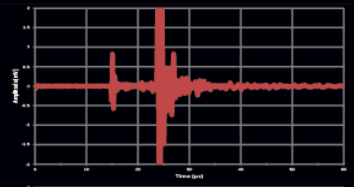
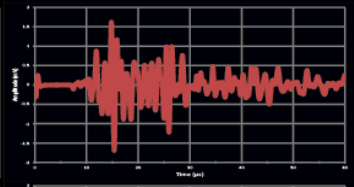
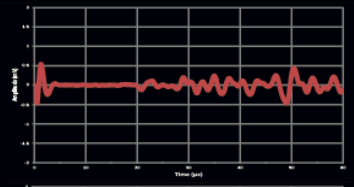
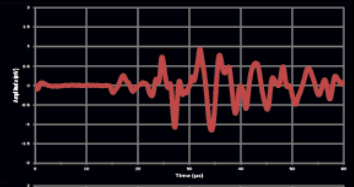
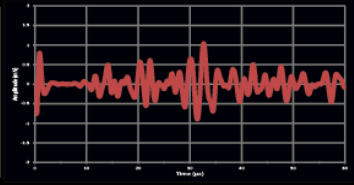
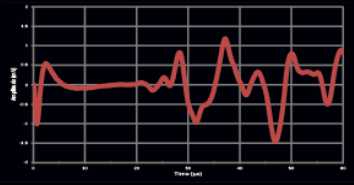
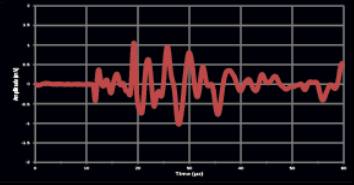
- Possible controls for the velocity:
  1) Sample Size/Quality of Wave Signature
  2) Frequency
  3) Orientation to Bedding & Degree of Laminations/Bioturbation
  4) Lithology
  5) Degree of Cementation
  6) Internal Fracturing of Samples

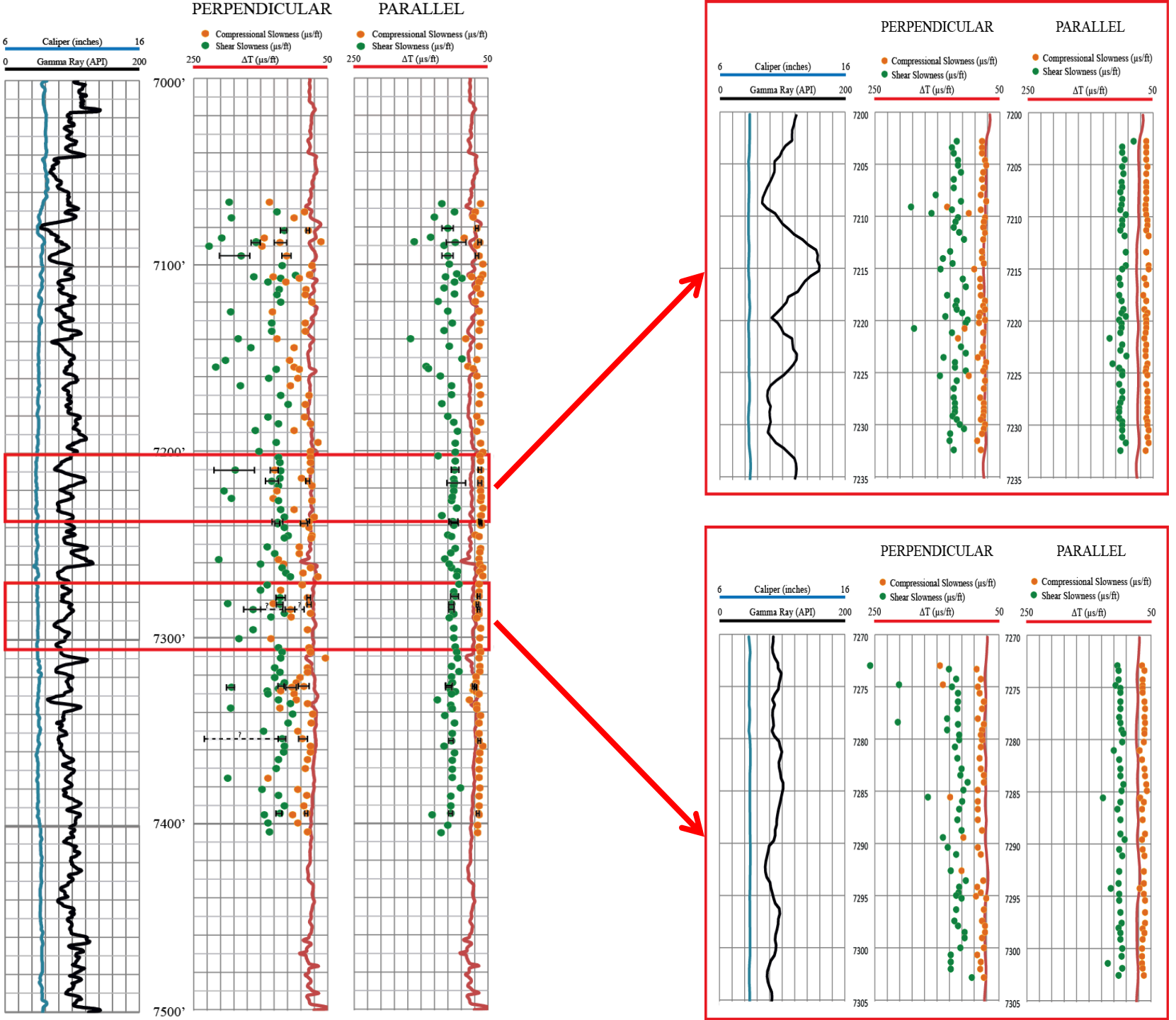

PERPENDICULAR
PARALLEL
Caliper (inches)
Gamma Ray (API)
Compressional Slowness (µs/ft)
Shear Slowness (µs/ft)
ΔT (µs/ft)
FASTER
7000'
7100'
7200'
7300'
7400'
7500'

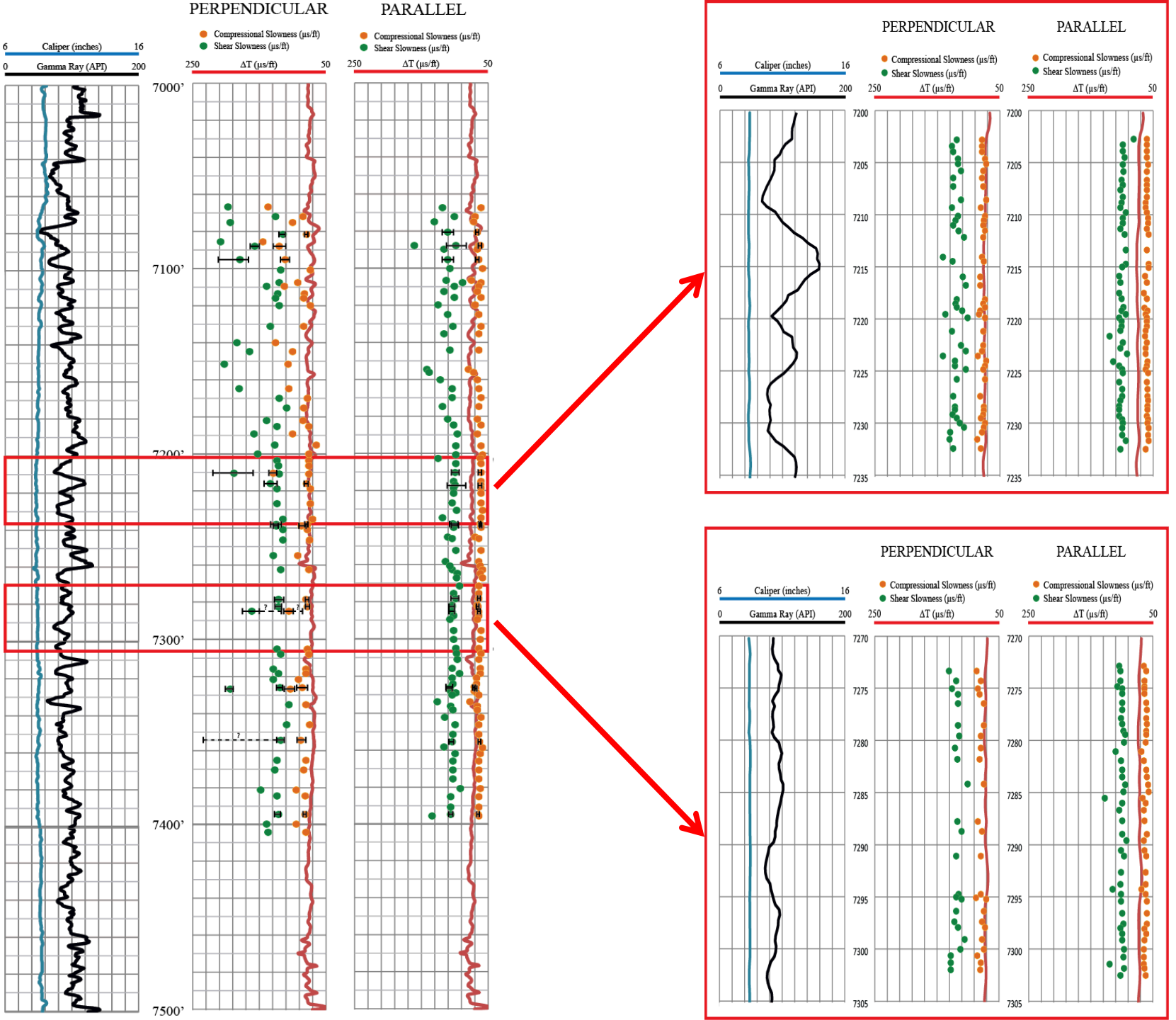






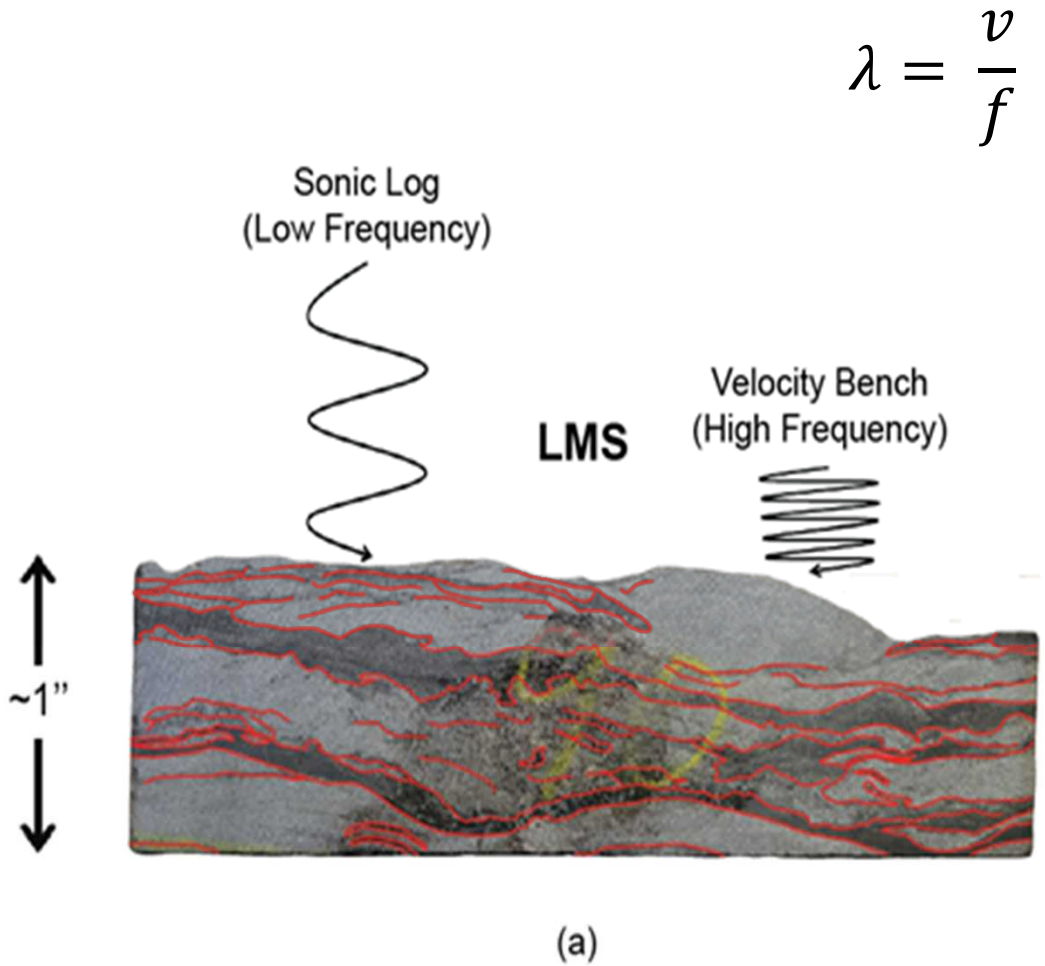
Facies	Vertical 1”	Vertical 2”	Horizontal
LMS			
HBMS			
BSM			
NSBM			
MBM			
FLM			
BFM			

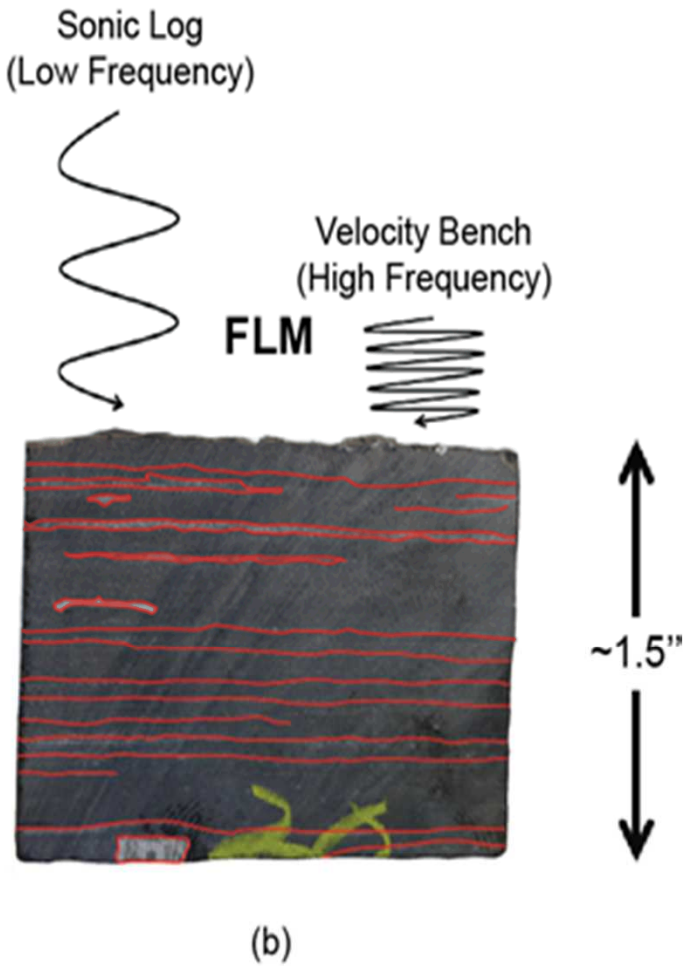

PERPENDICULAR
PARALLEL
Caliper (inches)
Gamma Ray (API)
Compressional Slowness (µs/ft)
Shear Slowness (µs/ft)
ΔT (µs/ft)
7000'
7100'
7200'
7300'
7400'
7500'


PERPENDICULAR
PARALLEL
Caliper (inches)
Gamma Ray (API)
Compressional Slowness (µs/ft)
Shear Slowness (µs/ft)
ΔT (µs/ft)
7000’
7100’
7200’
7300’
7400’
7500’
PERPENDICULAR
PARALLEL
PERPENDICULAR
PARALLEL

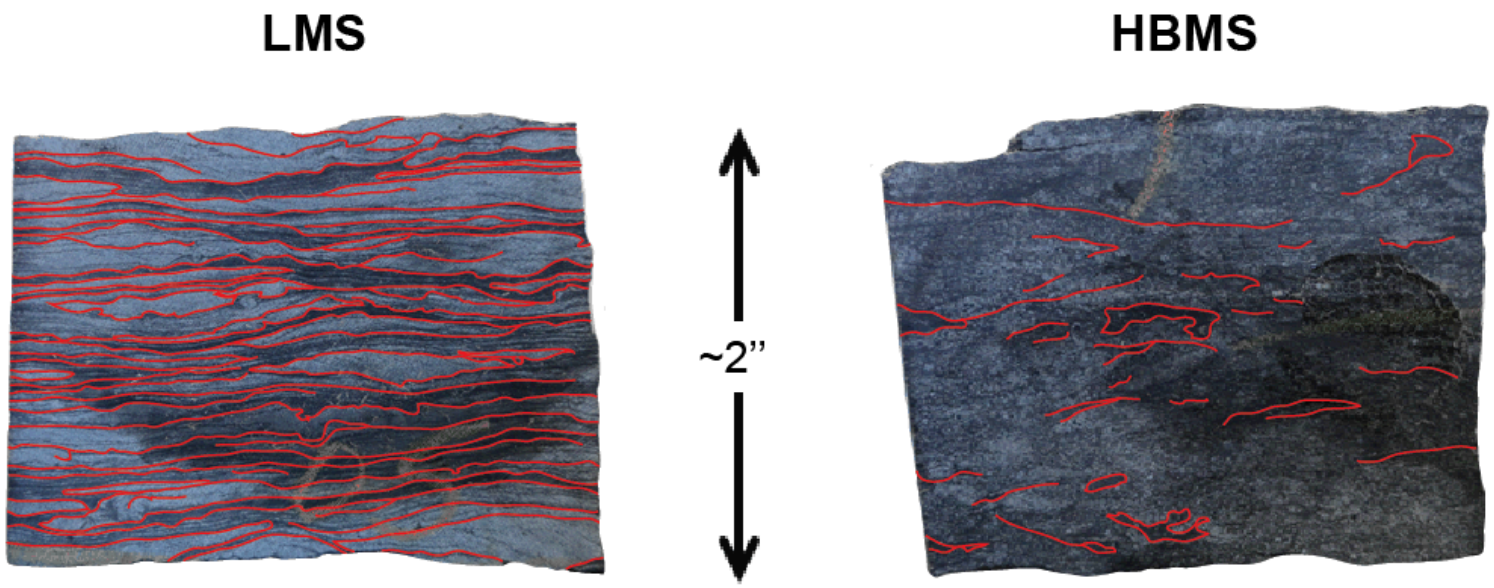
Sample Orientation to Bedding	Velocity (m/s)	Frequency (Hz)	Velocity Bench Wavelength (mm)	Sonic Log Wavelength (mm)
Perpendicular	3800	1 MHZ		
Perpendicular	4100	20 kHz		
Parallel	4800	1 MHz		
Parallel	4200	20 kHz		

$$\lambda = \frac{v}{f}$$





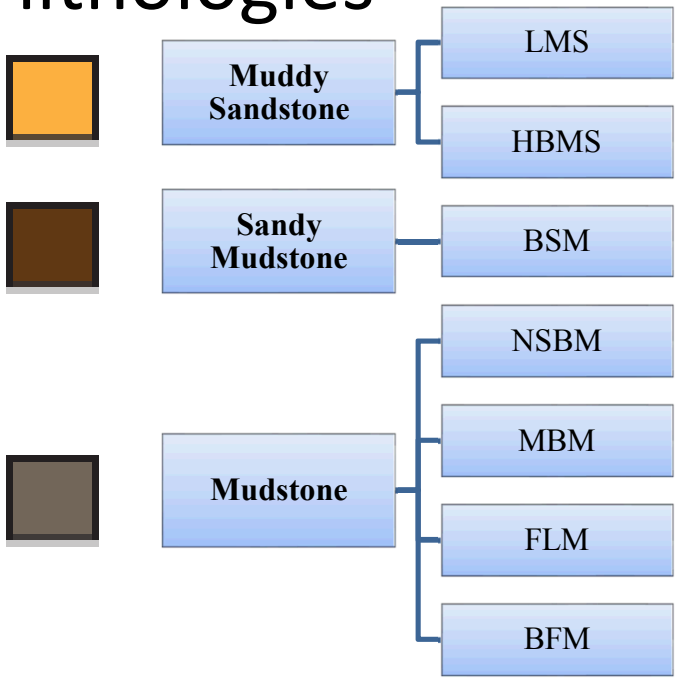
Orientation to Bedding & Degree of Lamination/Bioturbation

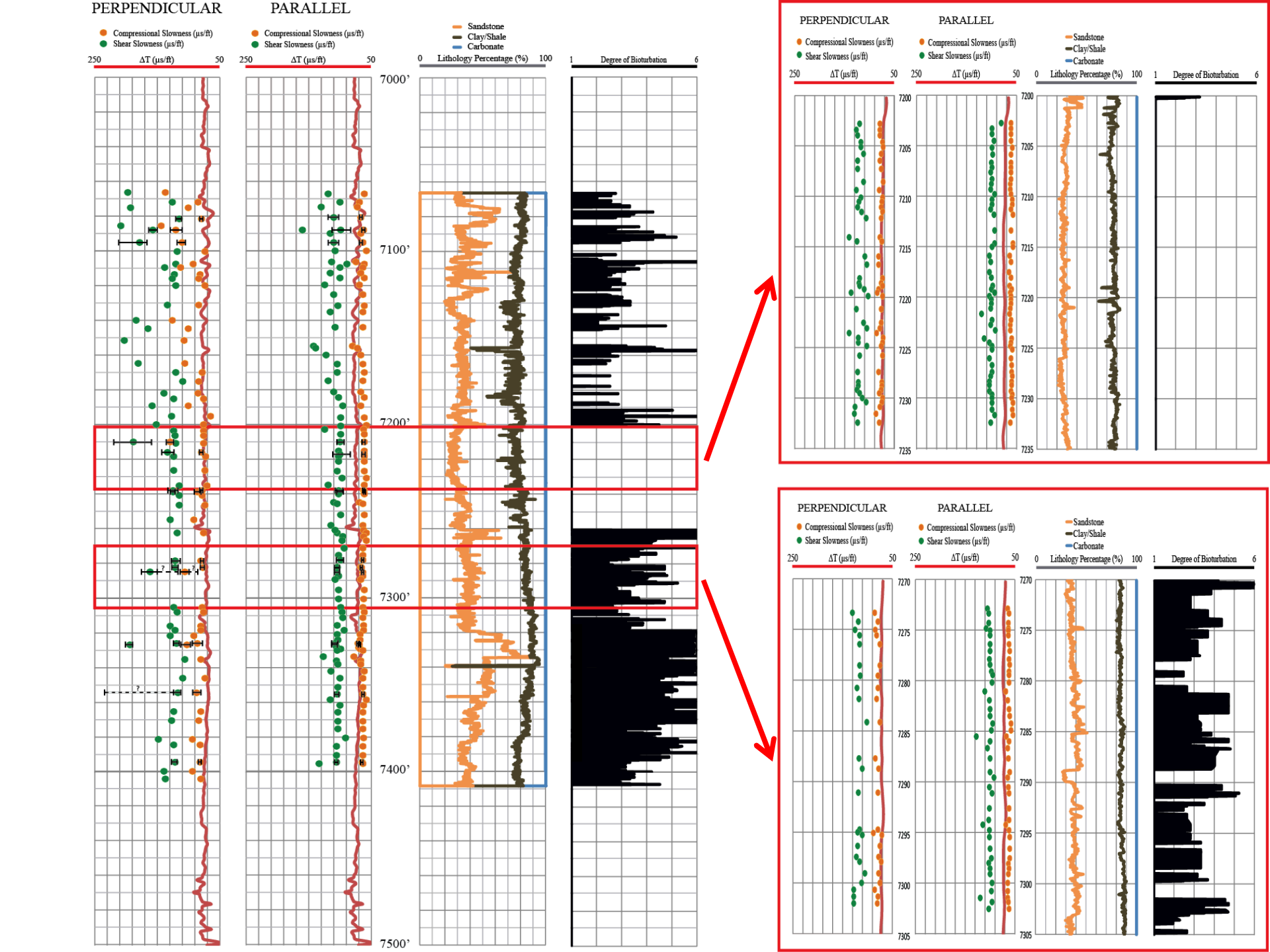


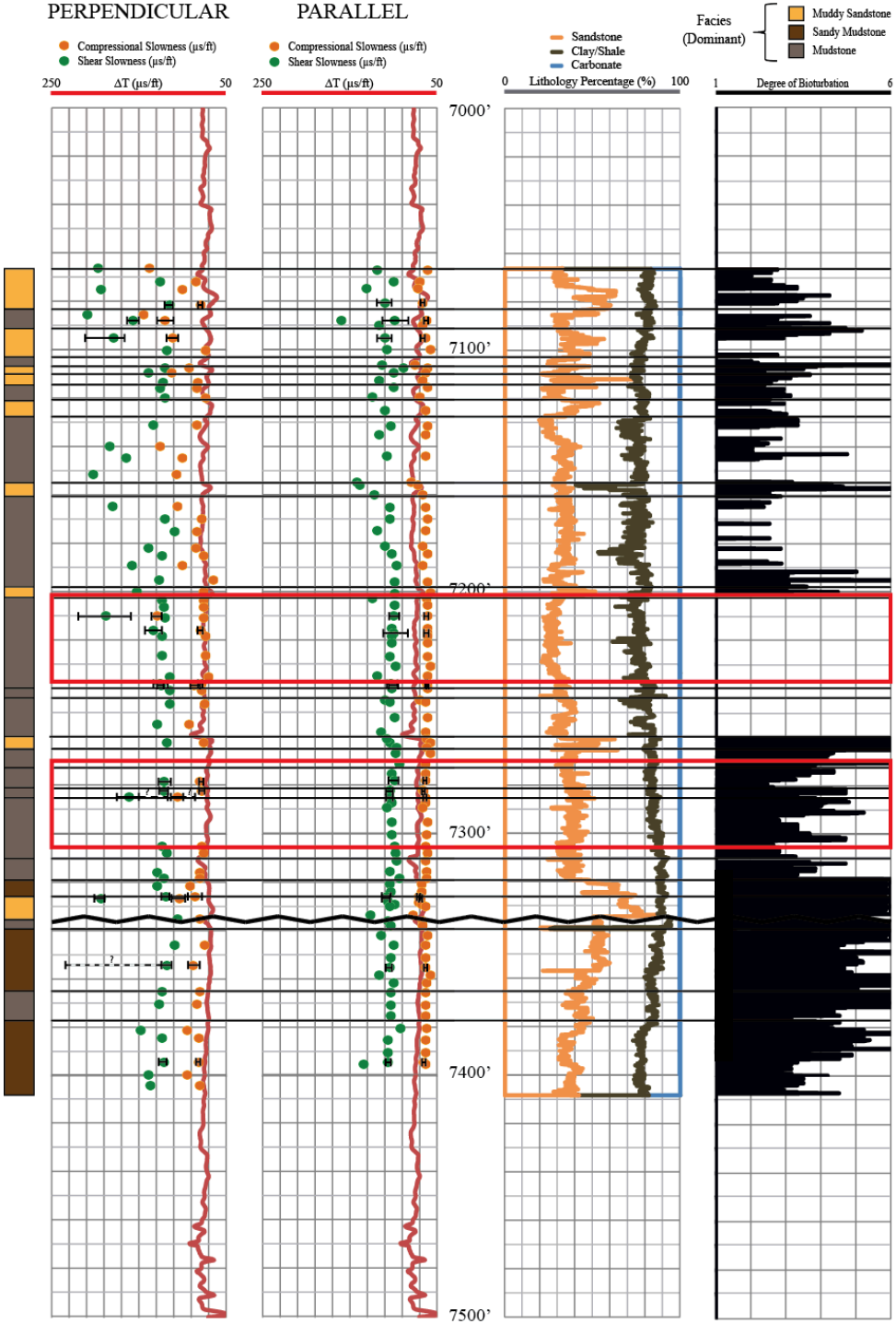
Lithology

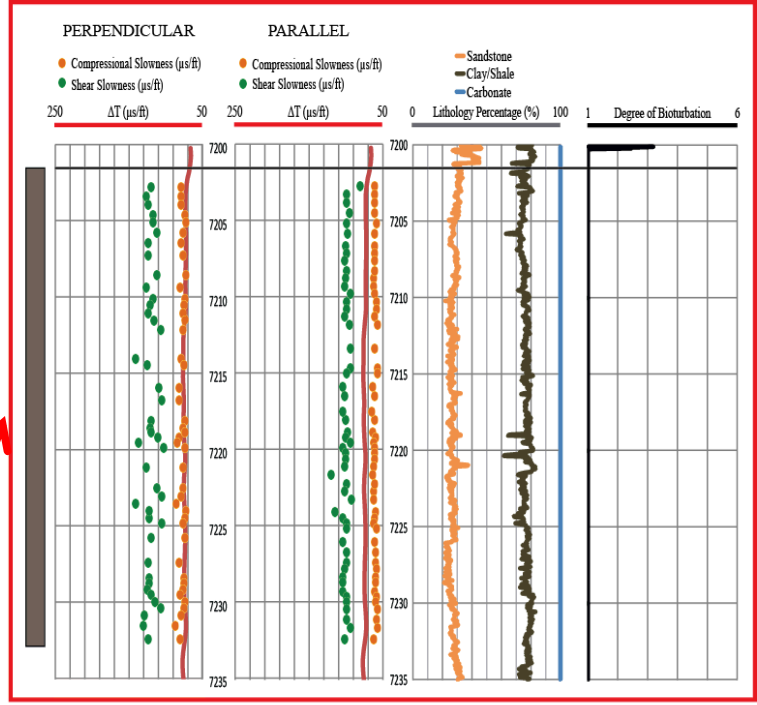
- Subtle differences in lithofacies not identified by velocity bench
- Detailed lithofacies can be condensed into three dominant lithologies

1) Muddy Sandstone
2) Sandy Mudstone
3) Mudstone

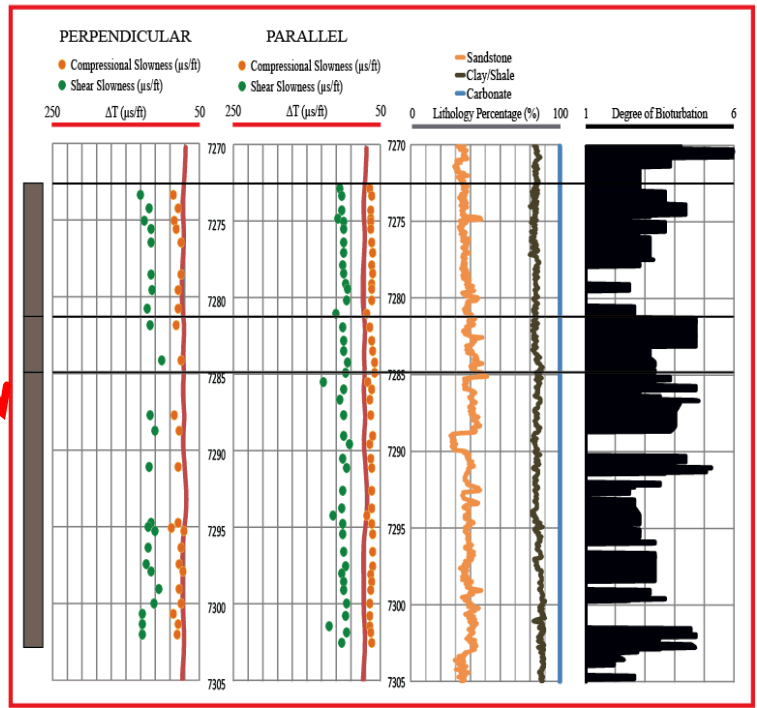



PERPENDICULAR
PARALLEL
Compressional Slowness (μs/ft)
Shear Slowness (μs/ft)
250
ΔT (μs/ft)
50
Sandstone
Clay/Shale
Carbonate
0
Lithology Percentage (%)
100
1
Degree of Bioturbation
6
7000'
7100'
7200'
7300'
7400'
7500'
7200
7205
7210
7215
7220
7225
7230
7235
7270
7275
7280
7285
7290
7295
7300
7305

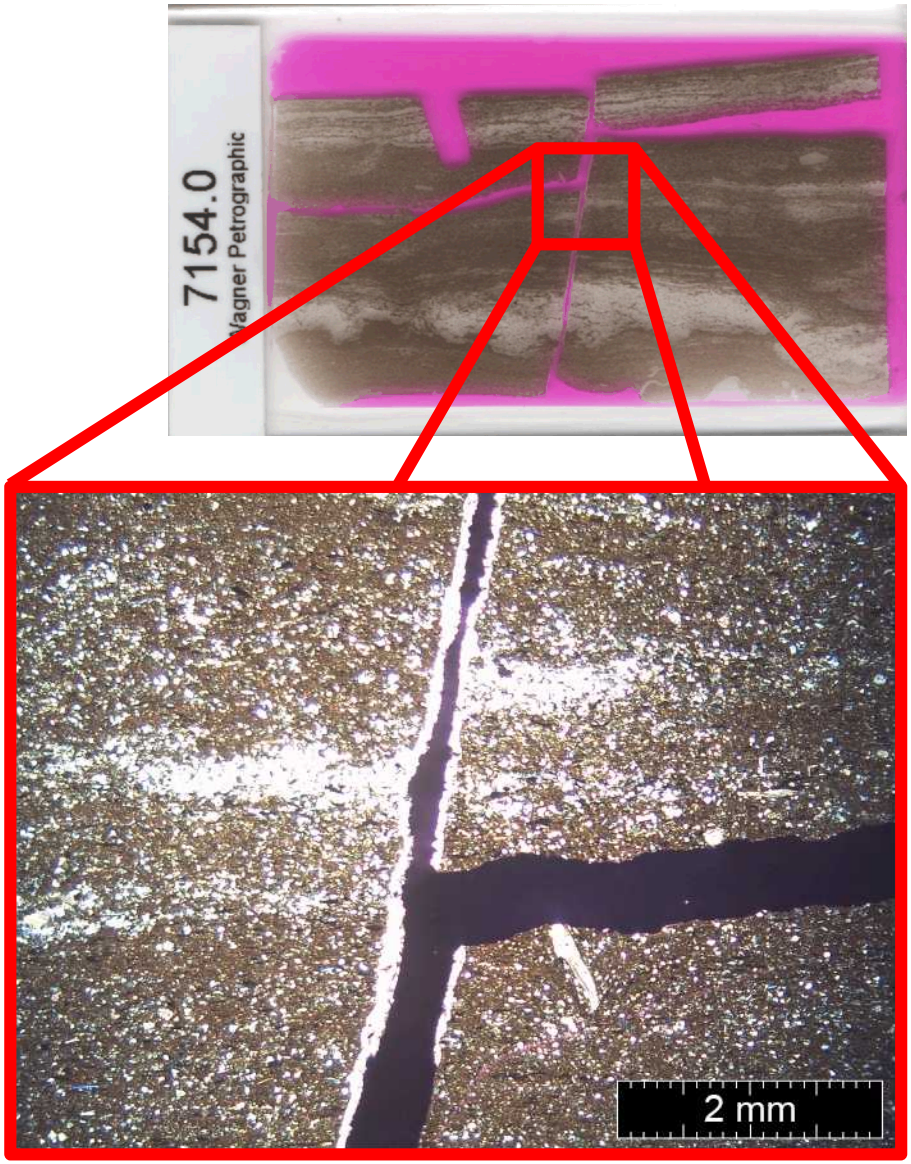


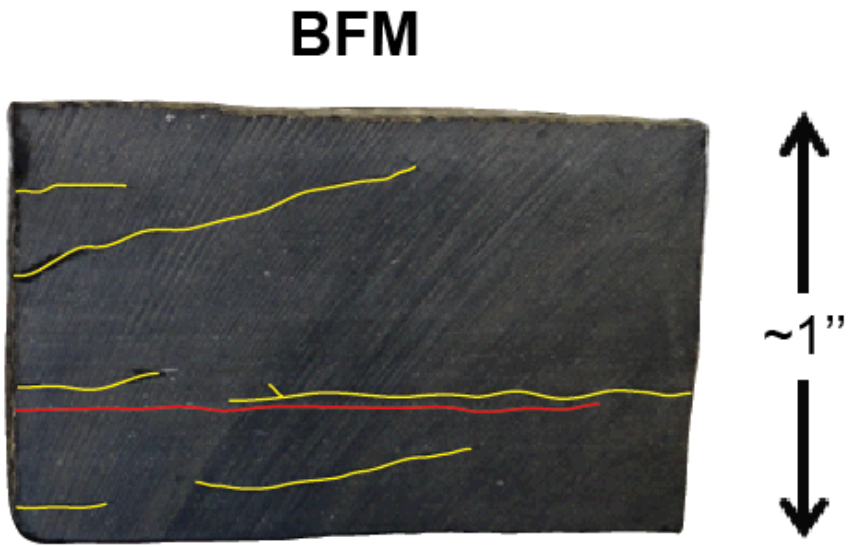


Dominant Facies Muddy Sandstone Sandy Mudstone Mudstone

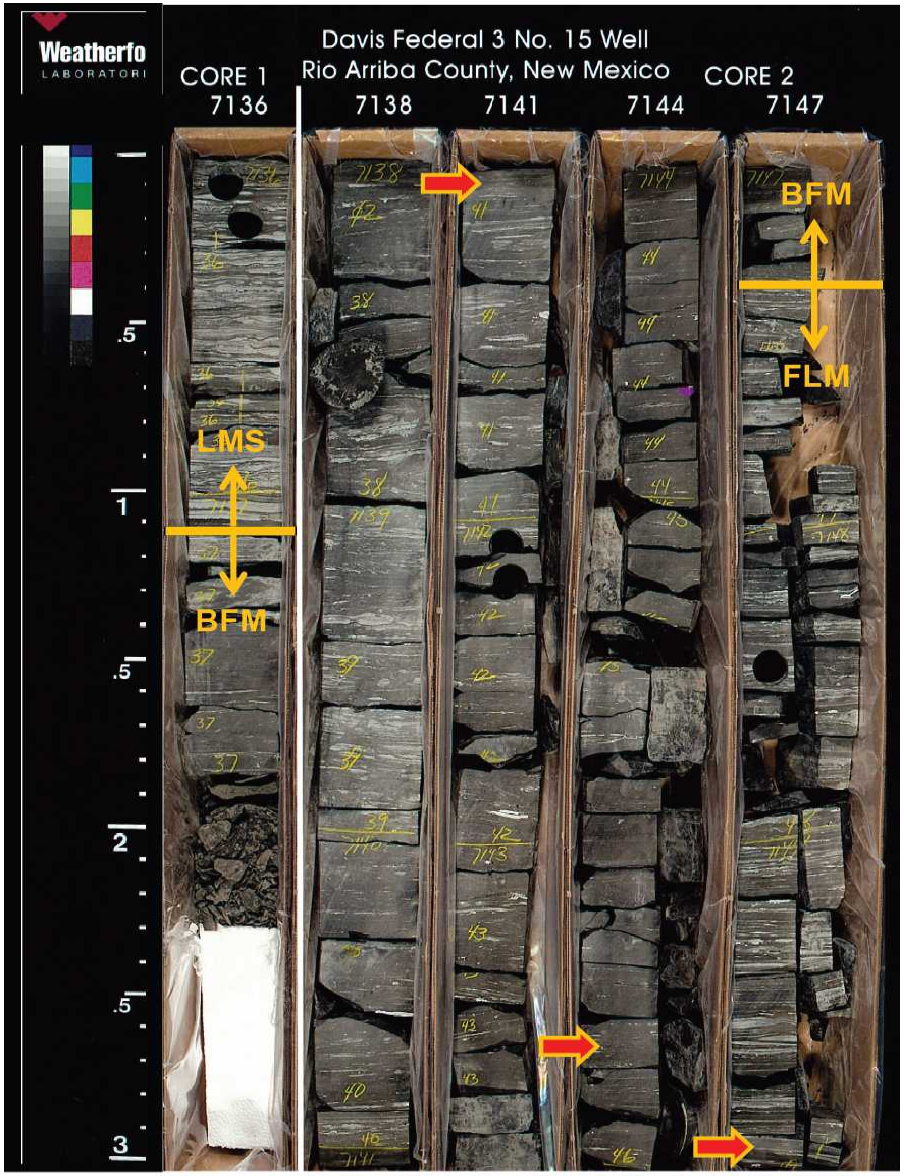


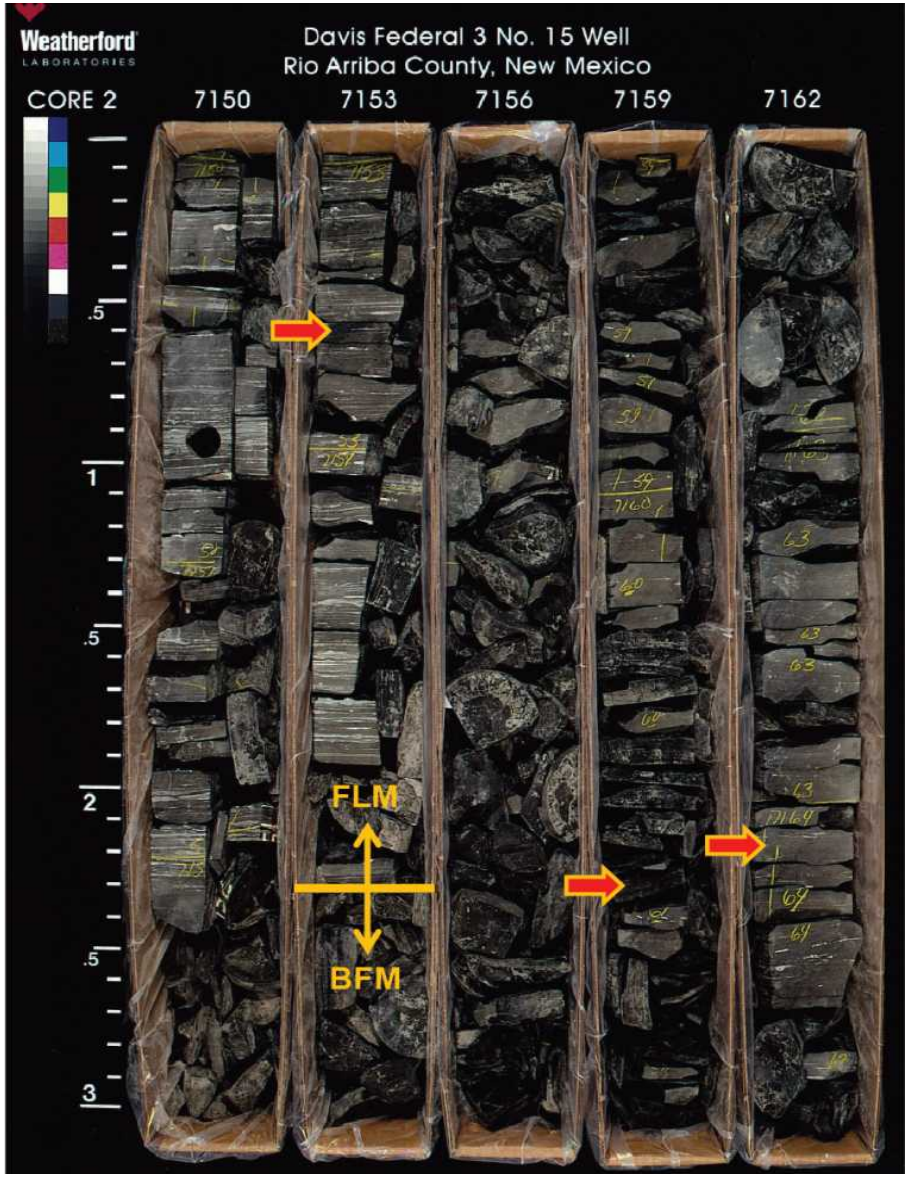
Cementation and Internal Fractures





Cementation and Internal Fractures

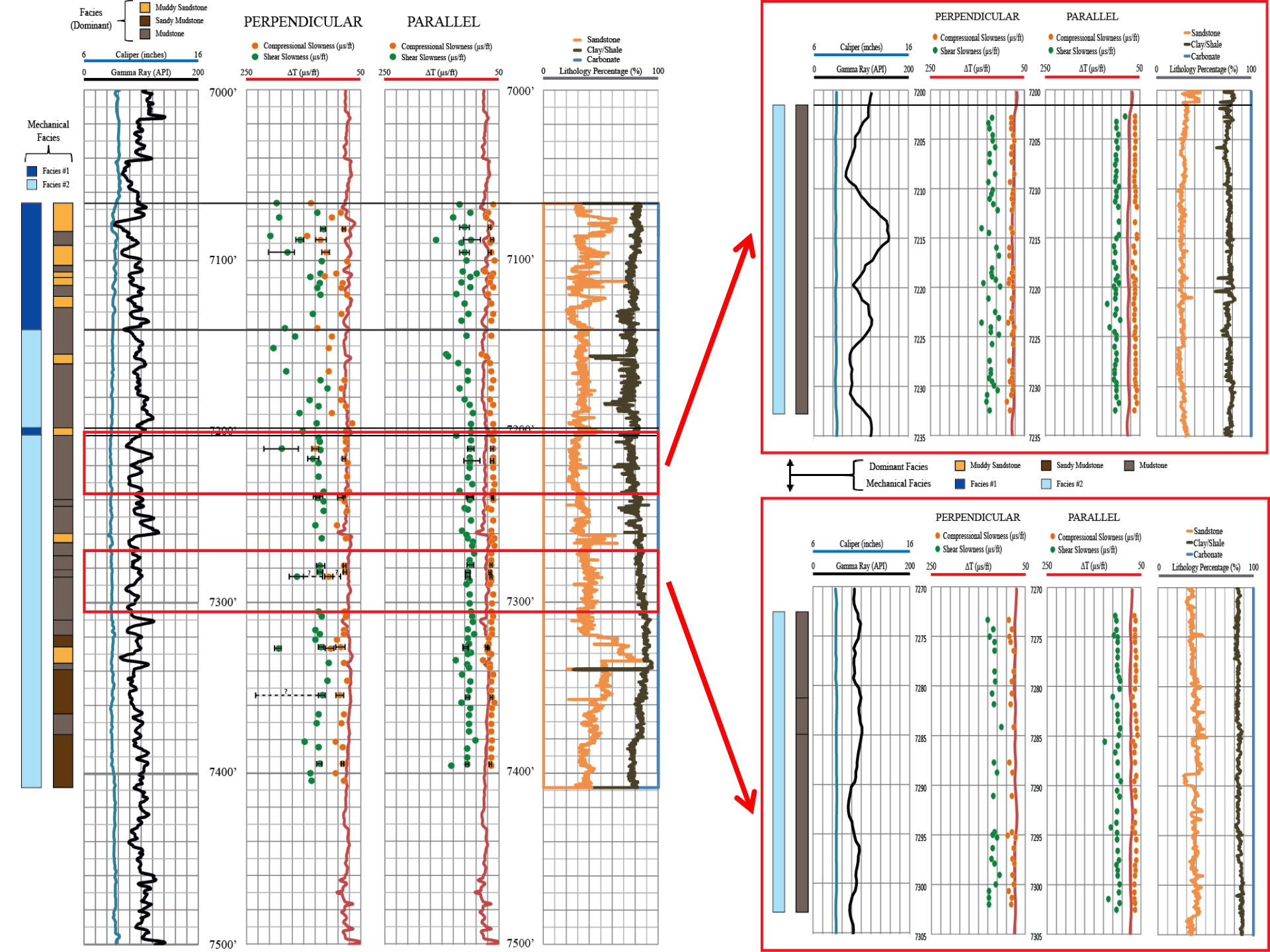




Mechanical Facies

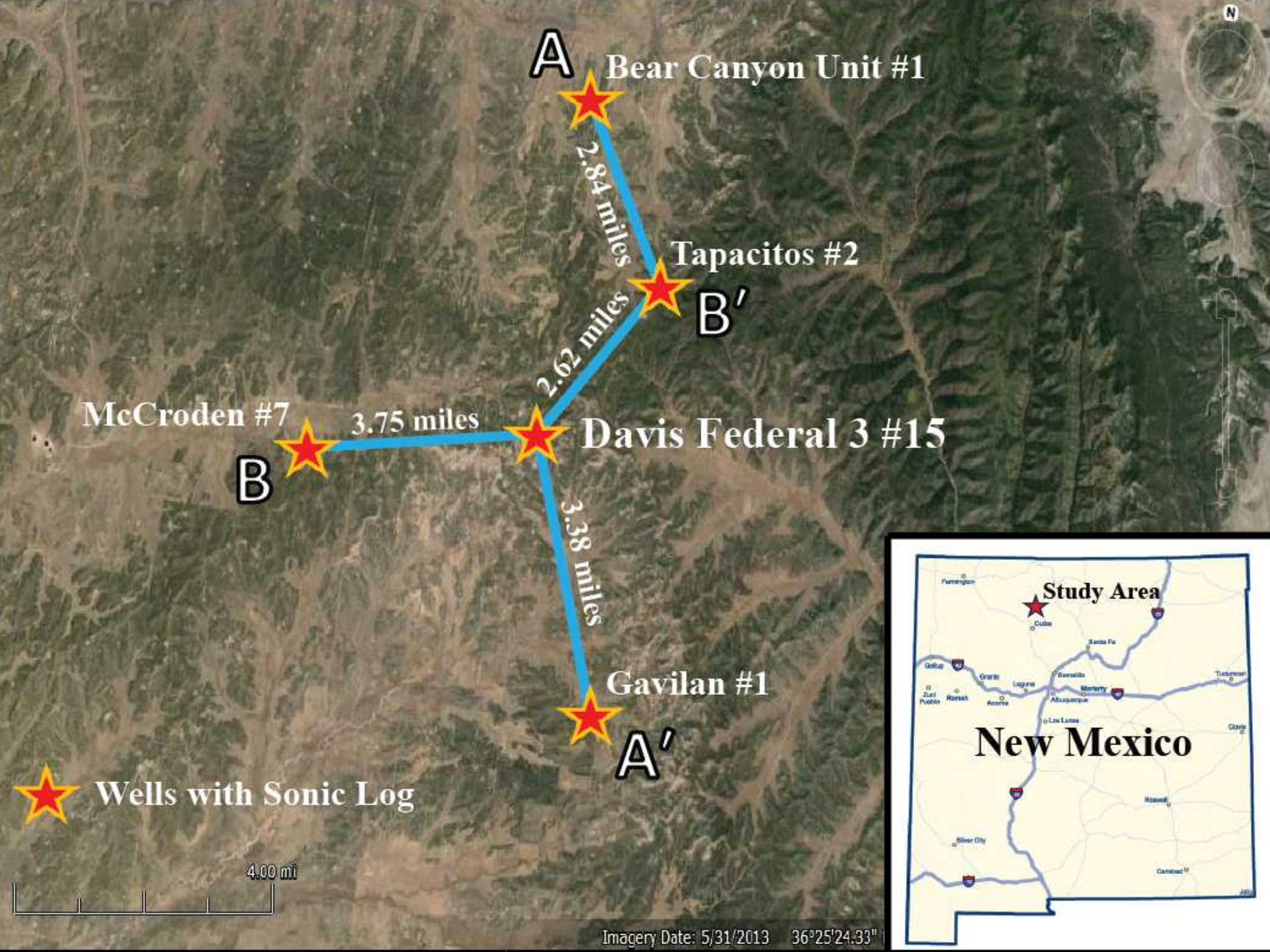
- Facies based on velocity fluctuations

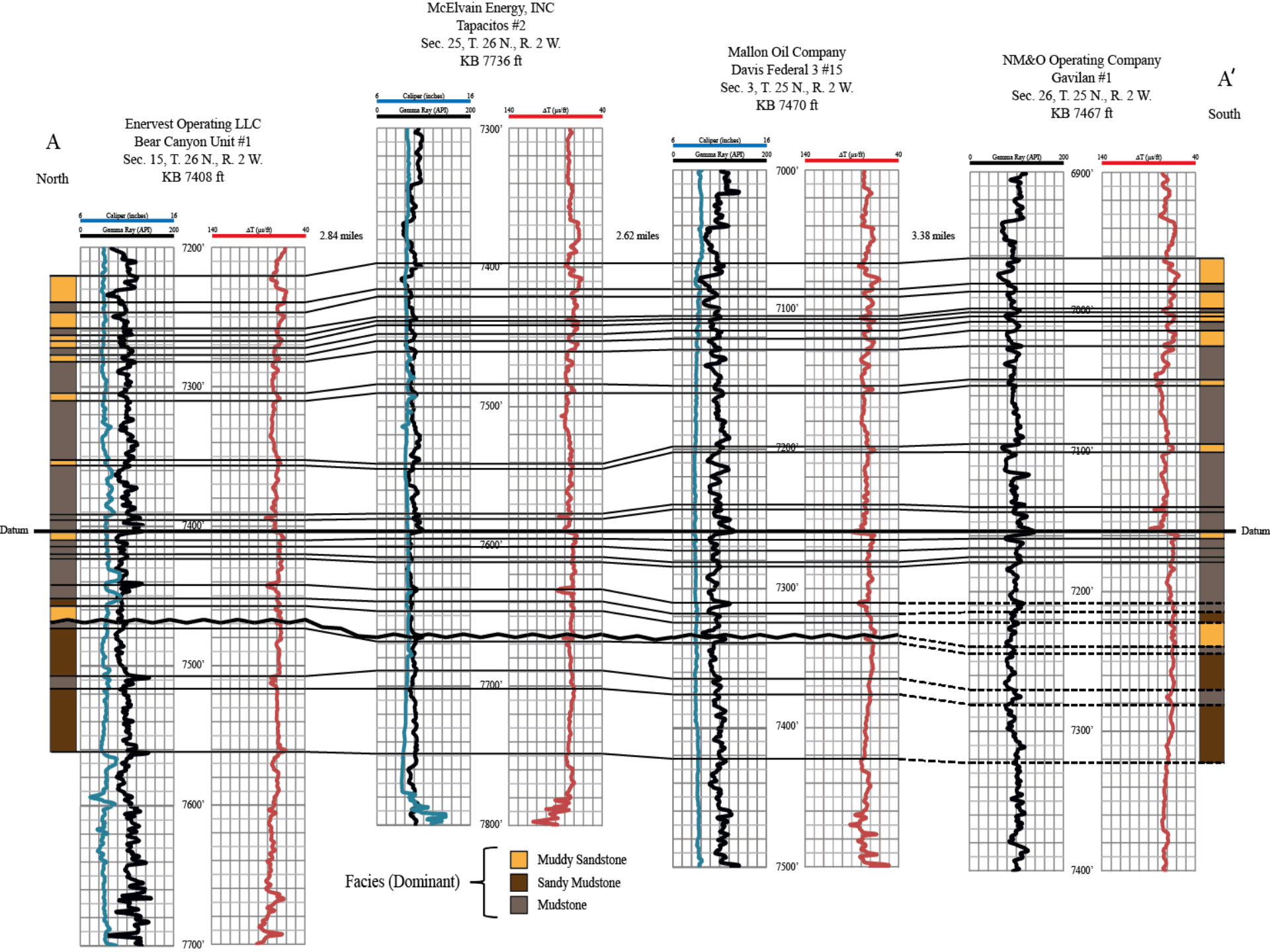
1) Facies #1
   - Most fluctuation observed between samples
2) Facies #2
   - Least fluctuation observed between samples

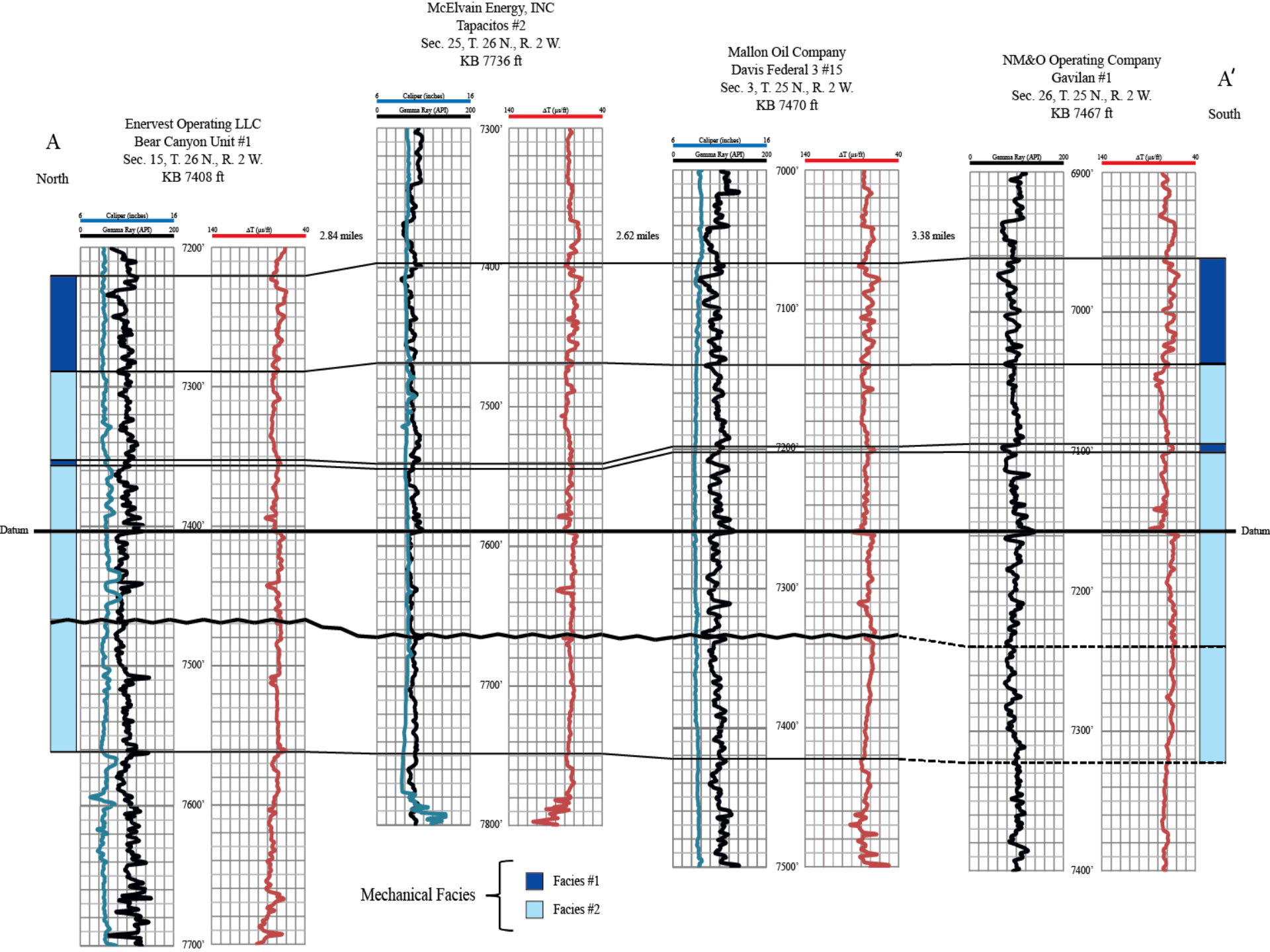

Facies (Dominant)
Muddy Sandstone
Sandy Mudstone
Mudstone
PERPENDICULAR
PARALLEL
Caliper (inches)
Gamma Ray (API)
Compressional Slowness (µs/ft)
Shear Slowness (µs/ft)
ΔT (µs/ft)
Sandstone
Clay/Shale
Carbonate
Lithology Percentage (%)
Mechanical Facies
Facies #1
Facies #2
7000'
7100'
7200'
7300'
7400'
7500'
Dominant Facies
Mechanical Facies

Identification of Facies in Subsurface

- Can facies be regionally extrapolated from Davis Federal 3 #15 data?
  - Dominant Lithology
  - Mechanical Facies


A
Bear Canyon Unit #1
2.84 miles
Tapacitos #2
B′
2.62 miles
McCroden #7
3.75 miles
Davis Federal 3 #15
B
3.38 miles
Gavilan #1
A′
Wells with Sonic Log
4.00 mi
Imagery Date: 5/31/2013 36°25'24.33"
Study Area
New Mexico

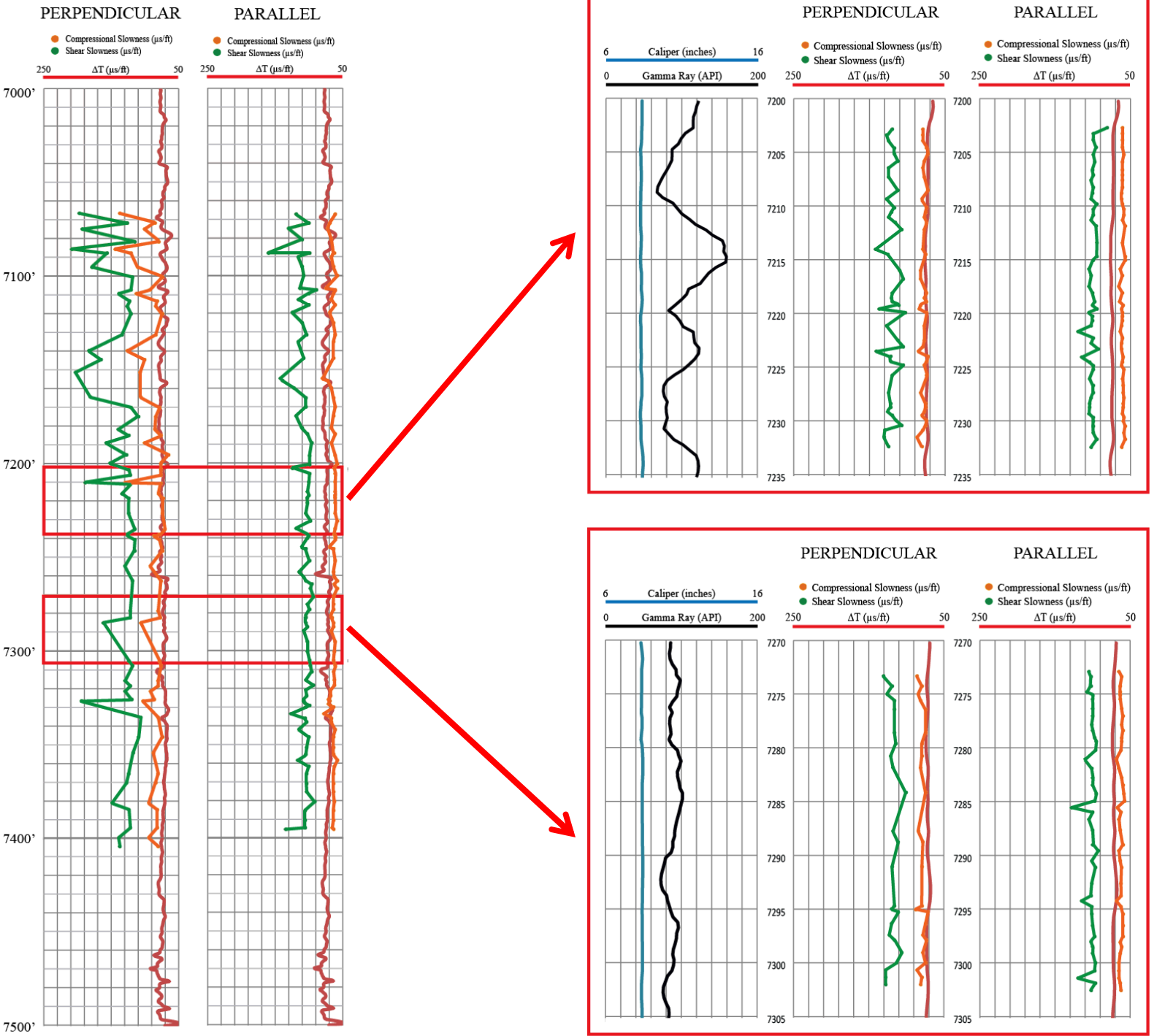

A
North
Enervest Operating LLC
Bear Canyon Unit #1
Sec. 15, T. 26 N., R. 2 W.
KB 7408 ft
McElvain Energy, INC
Tapacitos #2
Sec. 25, T. 26 N., R. 2 W.
KB 7736 ft
Mallon Oil Company
Davis Federal 3 #15
Sec. 3, T. 25 N., R. 2 W.
KB 7470 ft
NM&O Operating Company
Gavilan #1
Sec. 26, T. 25 N., R. 2 W.
KB 7467 ft
A′
South
Caliper (inches) 6 16
Gamma Ray (API) 0 200
ΔT (μs/ft) 140 40
2.84 miles
2.62 miles
3.38 miles
Datum
Facies (Dominant)
Muddy Sandstone
Sandy Mudstone
Mudstone

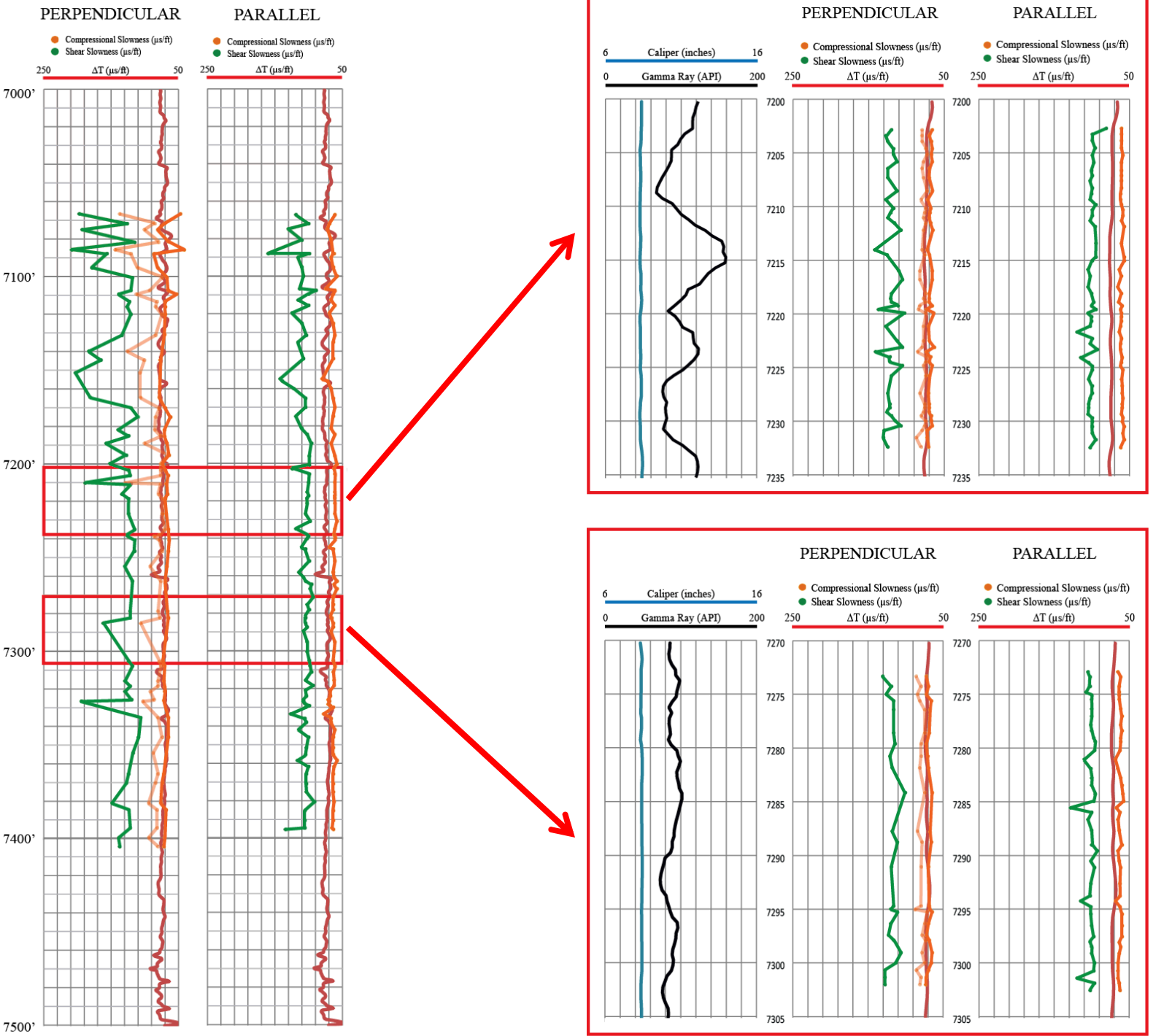

A
North
Enervest Operating LLC
Bear Canyon Unit #1
Sec. 15, T. 26 N., R. 2 W.
KB 7408 ft
McElvain Energy, INC
Tapacitos #2
Sec. 25, T. 26 N., R. 2 W.
KB 7736 ft
Mallon Oil Company
Davis Federal 3 #15
Sec. 3, T. 25 N., R. 2 W.
KB 7470 ft
NM&O Operating Company
Gavilan #1
Sec. 26, T. 25 N., R. 2 W.
KB 7467 ft
A′
South
Caliper (inches)
Gamma Ray (API)
ΔT (μs/ft)
2.84 miles
2.62 miles
3.38 miles
Datum
Datum
Mechanical Facies
Facies #1
Facies #2

Converting Surface Measurements into the Subsurface

- Can velocity measurements at surface conditions be approximated for the subsurface?
  - Gassmann Equation

Gassmann Equation


PERPENDICULAR
PARALLEL
Compressional Slowness (µs/ft)
Shear Slowness (µs/ft)
250
ΔT (µs/ft)
50
7000'
7100'
7200'
7300'
7400'
7500'
6
Caliper (inches)
16
0
Gamma Ray (API)
200
7200
7205
7210
7215
7220
7225
7230
7235
7270
7275
7280
7285
7290
7295
7300
7305


PERPENDICULAR
PARALLEL
Compressional Slowness (µs/ft)
Shear Slowness (µs/ft)
250
ΔT (µs/ft)
50
7000’
7100’
7200’
7300’
7400’
7500’
6
Caliper (inches)
16
0
Gamma Ray (API)
200
7200
7205
7210
7215
7220
7225
7230
7235
7270
7275
7280
7285
7290
7295
7300
7305

Conclusions

- Lithologic characteristics that have a major impact
  - Lithology
  - Degree of laminations/bioturbation
  - Orientation to bedding
- Lithologic characteristics that do not have impact
  - Degree of Cementation
  - Internal Fracturing of Samples

Conclusions (continued…)

- Subtle details between some lithofacies do not affect the velocity enough to distinguish
- Lithofacies and mechanical facies appear to regionally correlate
- Gassmann Equation
  - Compressional velocity is a good approximation of subsurface
  - Shear velocity is unclear

Suggestions for Future Research

- Triaxial testing under confining pressures for lithofacies samples to compare to our Gassmann calculations and the sonic log

- Measure velocities of lithofacies from nearby shale cores and compare to our results
  - Compare to our cross-section interpretations

Acknowledgements

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- Nels Iverson


Photo by Jeff Clay