Integrating Rock Physics and Seismic Modeling for Time-Lapse Analysis in a CO_2 Enhanced Oil Recovery Project*

Aaron Wandler[1], Paritosh Singh[1], and Thomas Davis[1]

Search and Discovery Article #40991 (2012)**
Posted August 13, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

[1]Colorado School of Mines, Golden, CO (awandler@mymail.mines.edu)

Abstract

Currently there are 128 enhanced oil recovery projects worldwide using CO_2 injection as a tertiary recovery method (Kootungal, 2010). When revitalizing mature oil fields using CO_2, it is important to monitor pore pressure and fluid saturation changes. Multi-component time-lapse seismic imaging has been advocated as a modern tool to interpret reservoir changes. To understand how pressure and fluid saturations influence compressional wave (P) and shear wave (S) velocities, five core samples are taken from the Morrow A sandstone formation at Postle Field, Texas County, Oklahoma. These samples represent high permeability, low permeability and cemented zones. We measured P- and S-wave velocities in the laboratory as a function of confining pressure, pore pressure and fluid type. The testing sequence begins with measuring each sample in the dry rock state and is followed by flushing each sample with brine, live oil, live oil with a 0.334 mol fraction of CO_2 and pure CO_2. This includes CO_2 in the gas and supercritical phase. The objective of these laboratory experiments is to determine the effect of pore pressure changes on the different lithological zones. The samples taken from the high permeability zone exhibit maximum sensitivity to changes in pore pressure. The P-wave velocity shows a response that is sensitive to both fluid saturation and pore pressure, whereas S-wave velocity is mainly sensitive to pore pressure. In addition, the S-wave velocity shows a greater sensitivity to changes in pore pressure than P-wave velocity.

We use the fluid and stress response measured from the core samples to modify velocity well logs through a log facies model correlation. The modified well logs represent the brine and CO_2 saturated cases at minimum and maximum reservoir pressure. These well logs are used for full waveform seismic modeling. For both the brine and CO_2 saturated cases, the P-wave response shows a maximum time-lapse amplitude difference at near offsets. Whereas the S-wave response shows a maximum time-lapse amplitude difference at near offsets for the brine case and at far offsets for the CO_2 saturated case. This demonstrates the

advantage of using offset limited stacks for time-lapse analysis as compared to full offset stacks. The seismic modeling results, verified and calibrated to the laboratory core measurements, demonstrate the importance of multi-component time-lapse seismic data for reservoir monitoring.

References

Bowen, D.W., and P. Weimer, 2003, Regional sequence stratigraphic setting and reservoir geology of Morrow incised-valley standsontes (lower Pennsylvanian), eastern Colorado and western Kansas: AAPG Bulletin, v. 87, p. 781-815.

Jobe, T.D., 2009, Optimizing geo-cellular reservoir modeling in a braded river incised valley fill: Postle Field, Texas County, Oklahoma: M.S. thesis, Colorado School of Mines, Golden, Colorado, (2010).

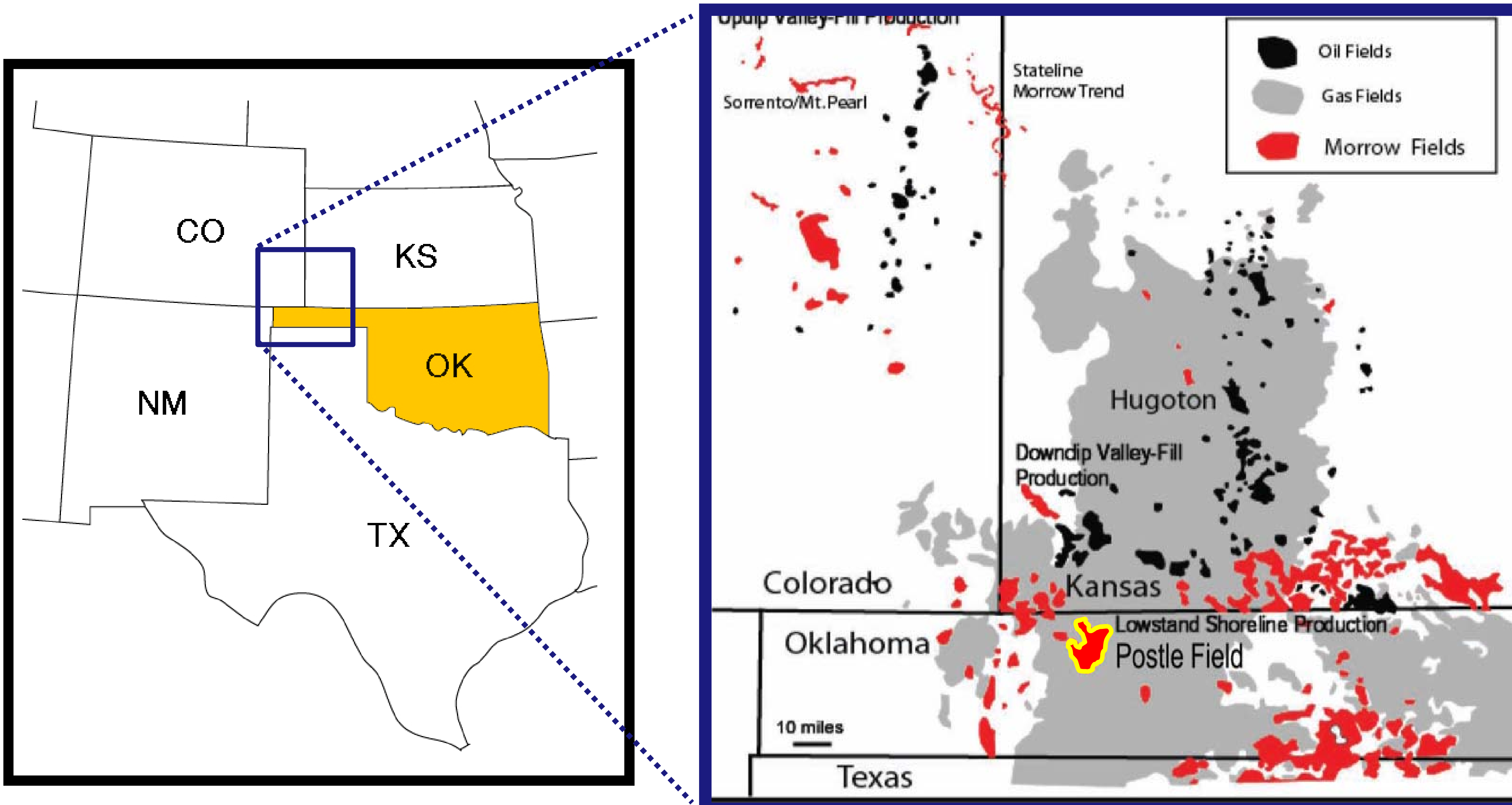
Kootungal, L., 2010, World-wide EOR survey: Oil and Gas Journal, v. 108/14, p. 41-53.

Singh, P. and T. Davis, 2010 (2011), Advantages of shear wave seismic in Morrow sandstone detection: International Journal of Geophysics, v. 2011, 16 p.

Integrating Rock Physics and Seismic Modeling for Time-Lapse Analysis in a CO_2 Enhanced Oil Recovery Project

Aaron Wandler*, Paritosh Singh, Thomas Davis
Reservoir Characterization Project
Department of Geophysics
Colorado School of Mines

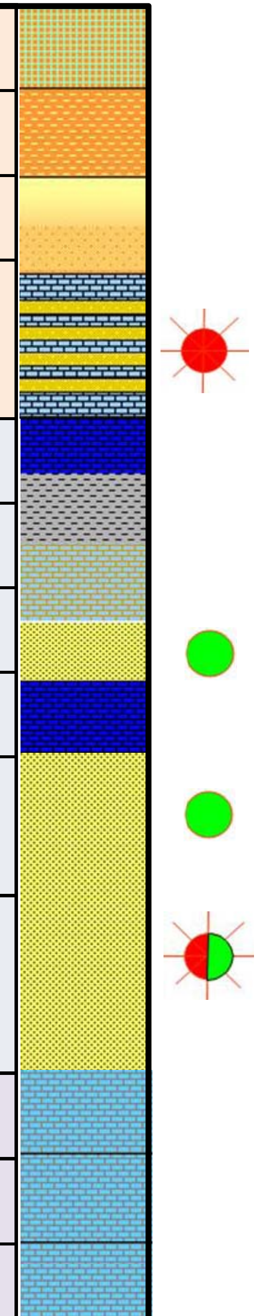
Location of Postle Field



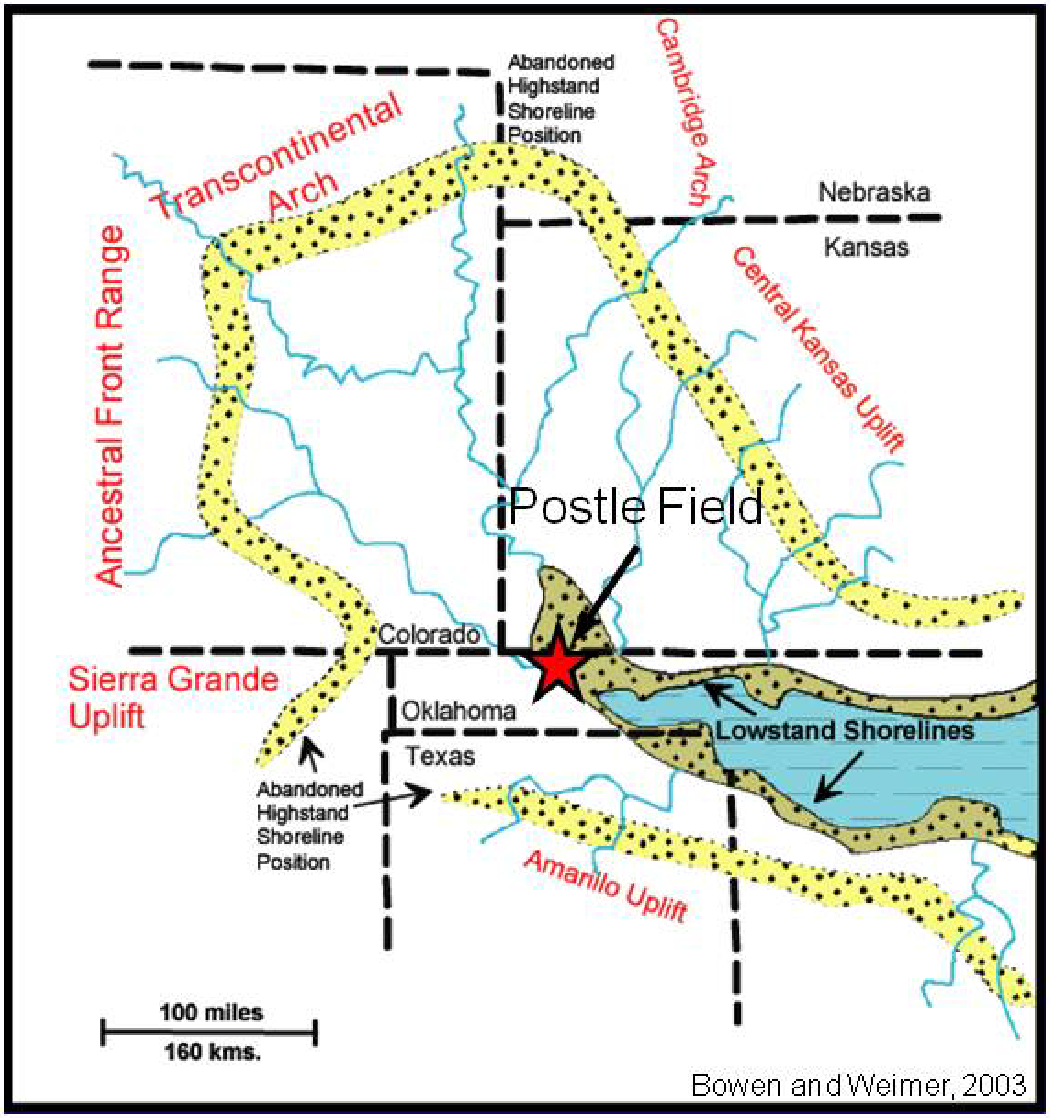
Modified from Bowen and Weimer 2003

Stratigraphy

Permian *Hugoton*	Ochoan	
	Gaudalupian	El Reno
	Leaonardian	Summer / Enid
	Wolfcampian	Chase Council Grove Admire
Pennsylvanian	Virgilian	Wabaunsee Shawnee
	MIssourian	Lansing Kansas city
	Des Moines	Marmaton Cherokee
	Atoka	13 Fingers
	Upper Morrow	**A Sand** A1 Sand A2 Sand
	Lower Morrow	B Sand F Sand G Sand Keys
Missis-sippian	Chester	Chester
	Meramac	
	Osange	

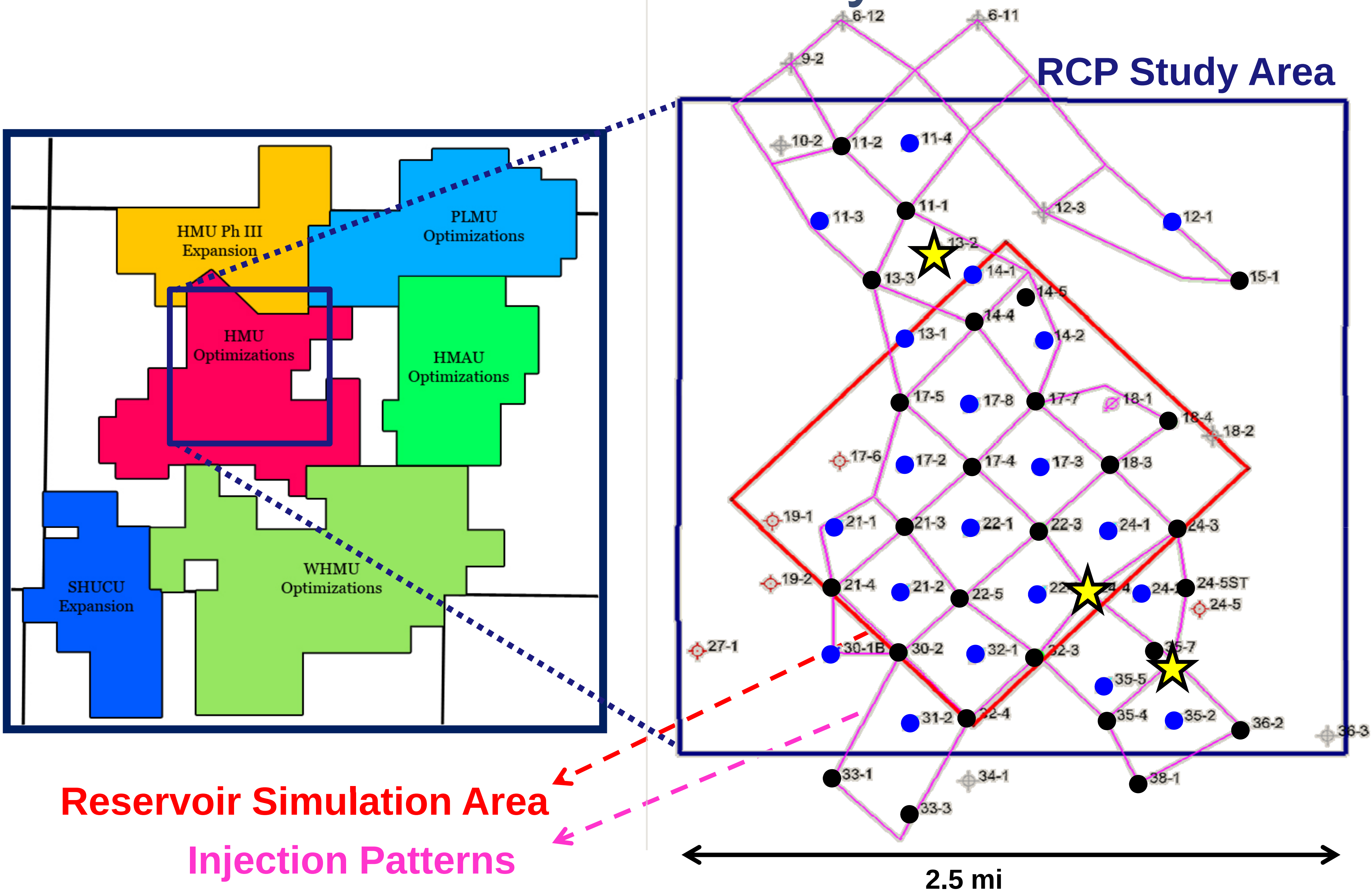


Morrowan Paleogeography



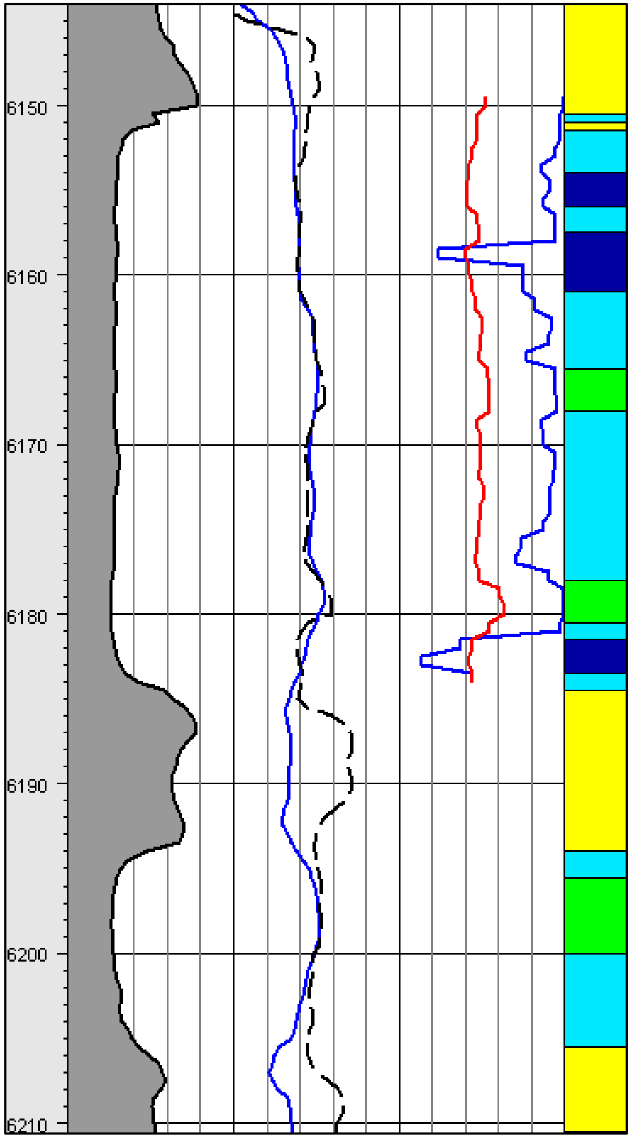
Presenter's Notes: Deposition of Morrow sand Postle Field occurred during a relative sea level lowstand, typical Morrow sediments consist of shales punctuated by valley fill sand deposits.

Production Units and Study Area

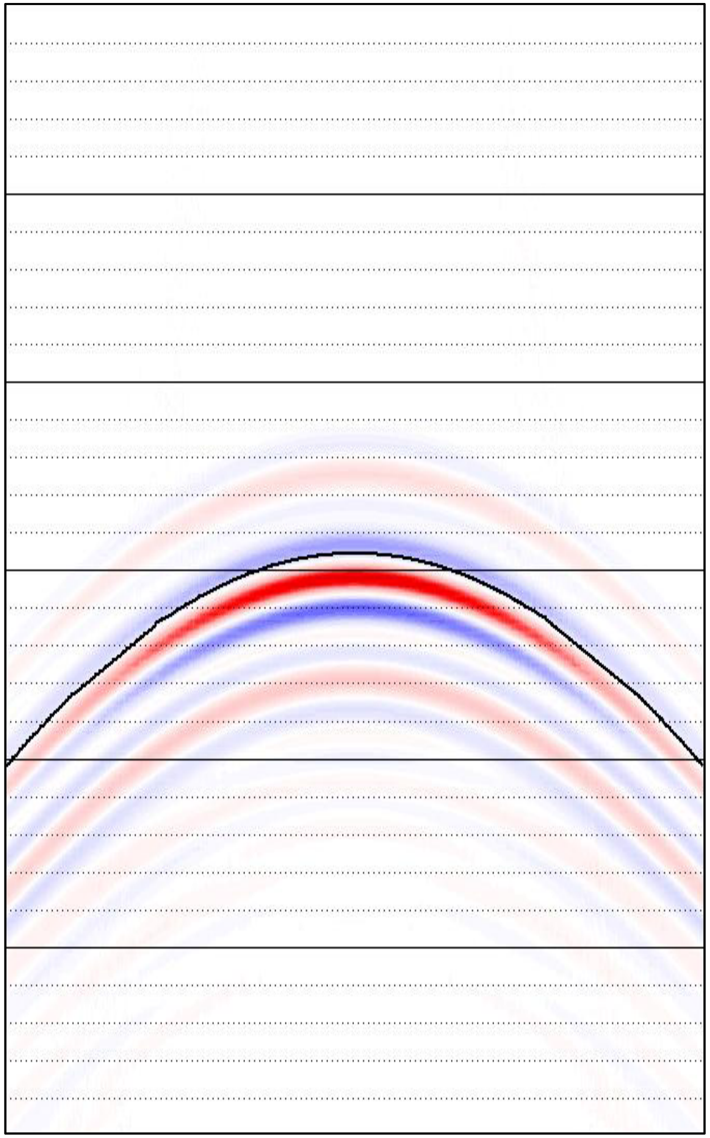


Core

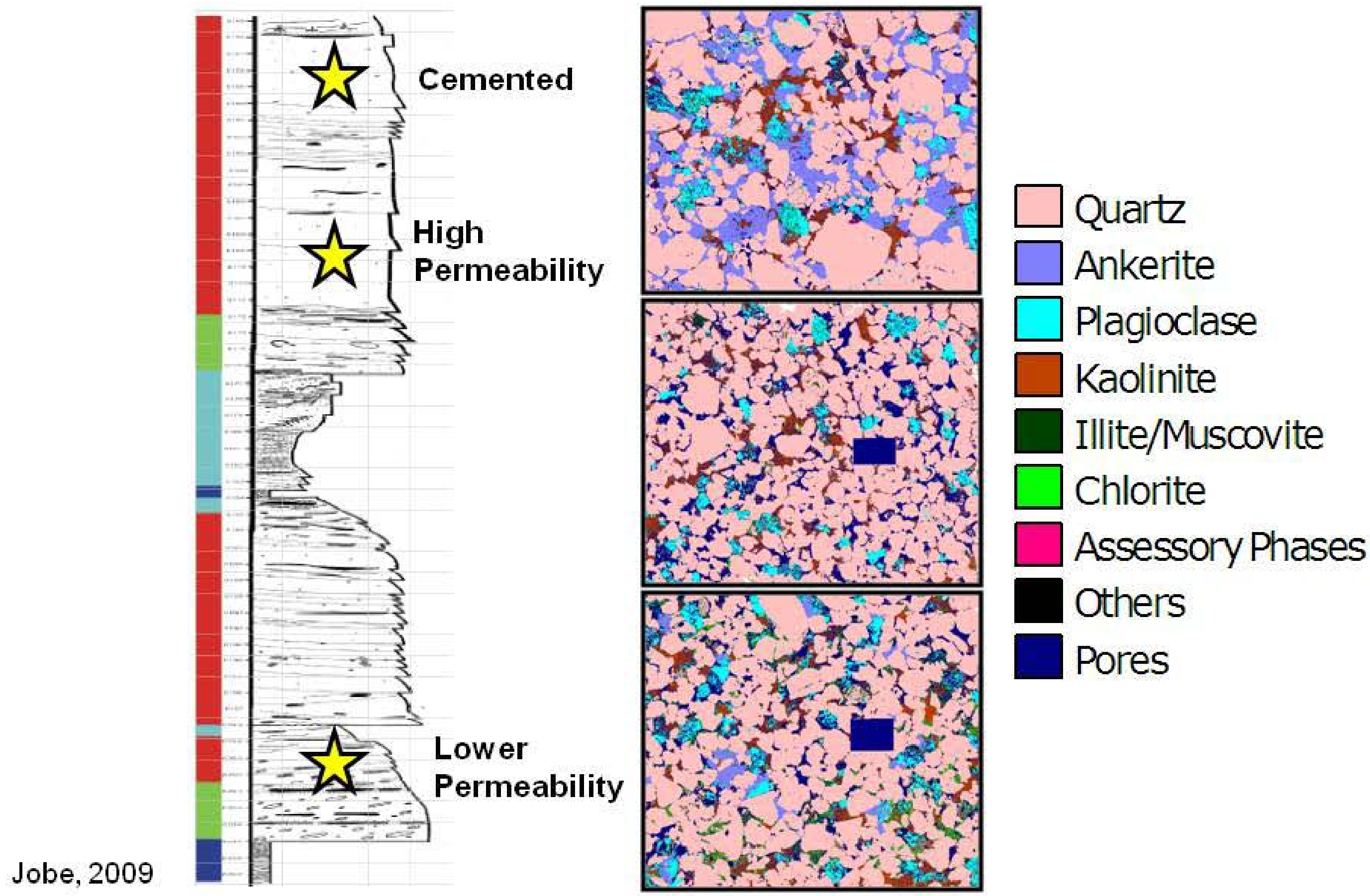
Well Logs



Seismic Modeling

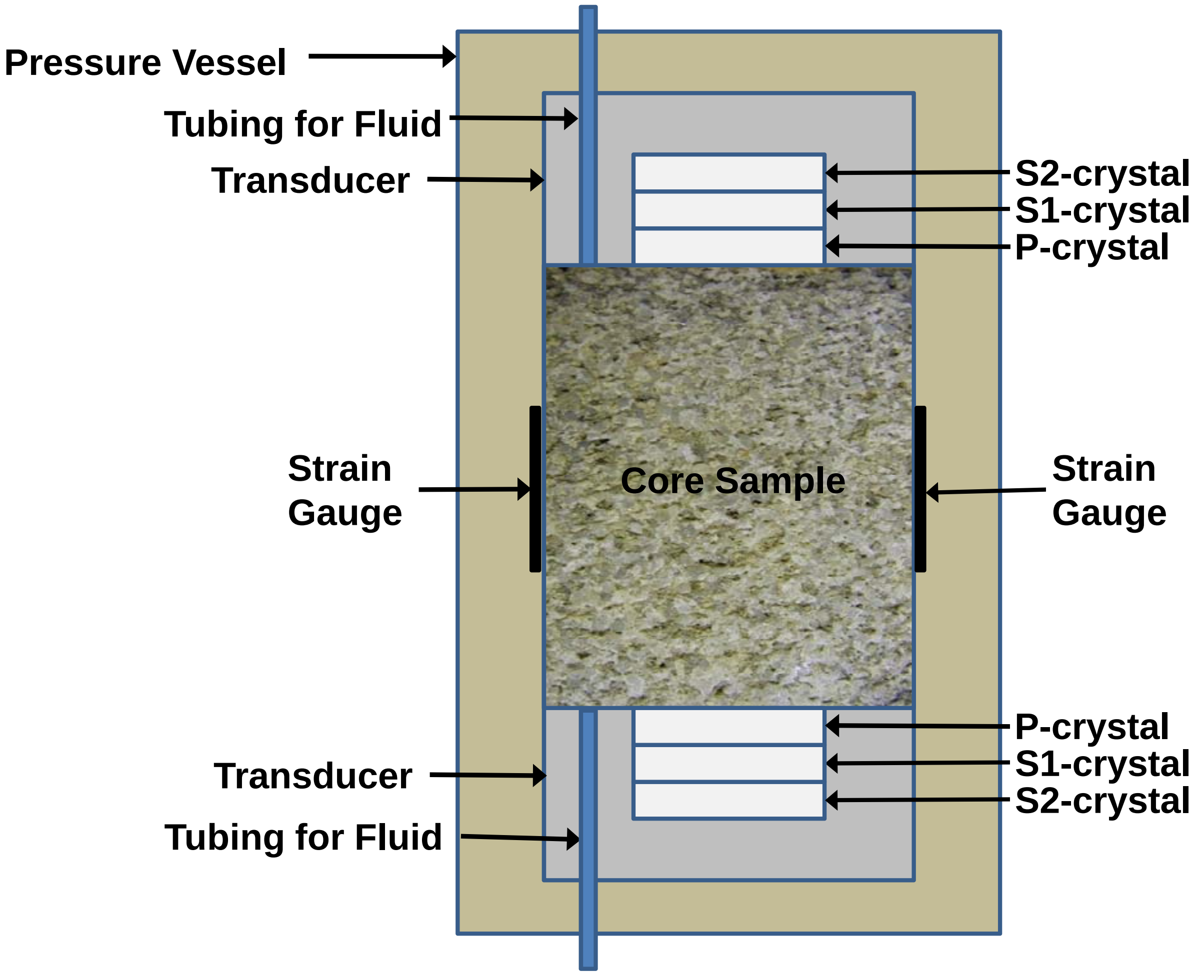


Mineralogy



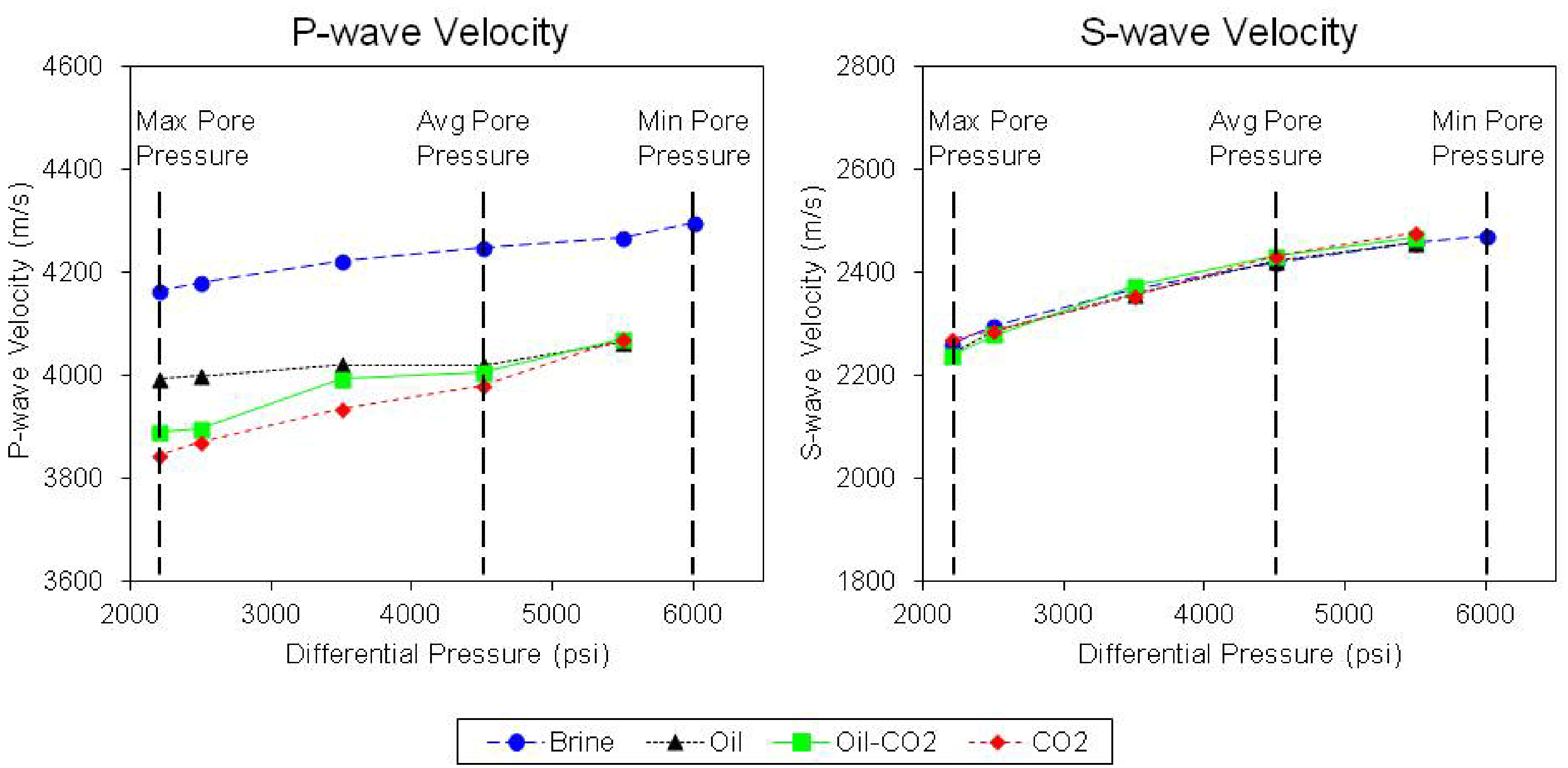
Presenter's Notes: Cemented: Detrital – eroded and transported, will help determine depositional environment. Not as much grain-to-grain contact as in the other samples – possibly early cementation Considerable amount of Ankerite, which could indicate that the pore water(s) was rich in either Fe or Mg or Mn. Possible quartz overgrowth – angular overgrowths over subrounded quartz grains. Most of the pores occur as interstitial space in between fine-grained kaolinite clay. High Perm: Most of the porosity occurs as openings between quartz grains. Subrounded quartz grains – transport distance from provenance. Mature – High percentage of quartz grains which are the most resistant. Kaolinite known to reduce porosity has a lesser effect on perm. Illite known to have little effect on porosity known to reduce perm. Plagioclase – less resistant to erosion. Unlike samples B and F, only a trace amount of ankerite occurs as cement. Low Perm: More similar to the first sample. Most of the pore space occurs as interstitial space in between fine-grained kaolinite and chlorite.

Laboratory Experiment



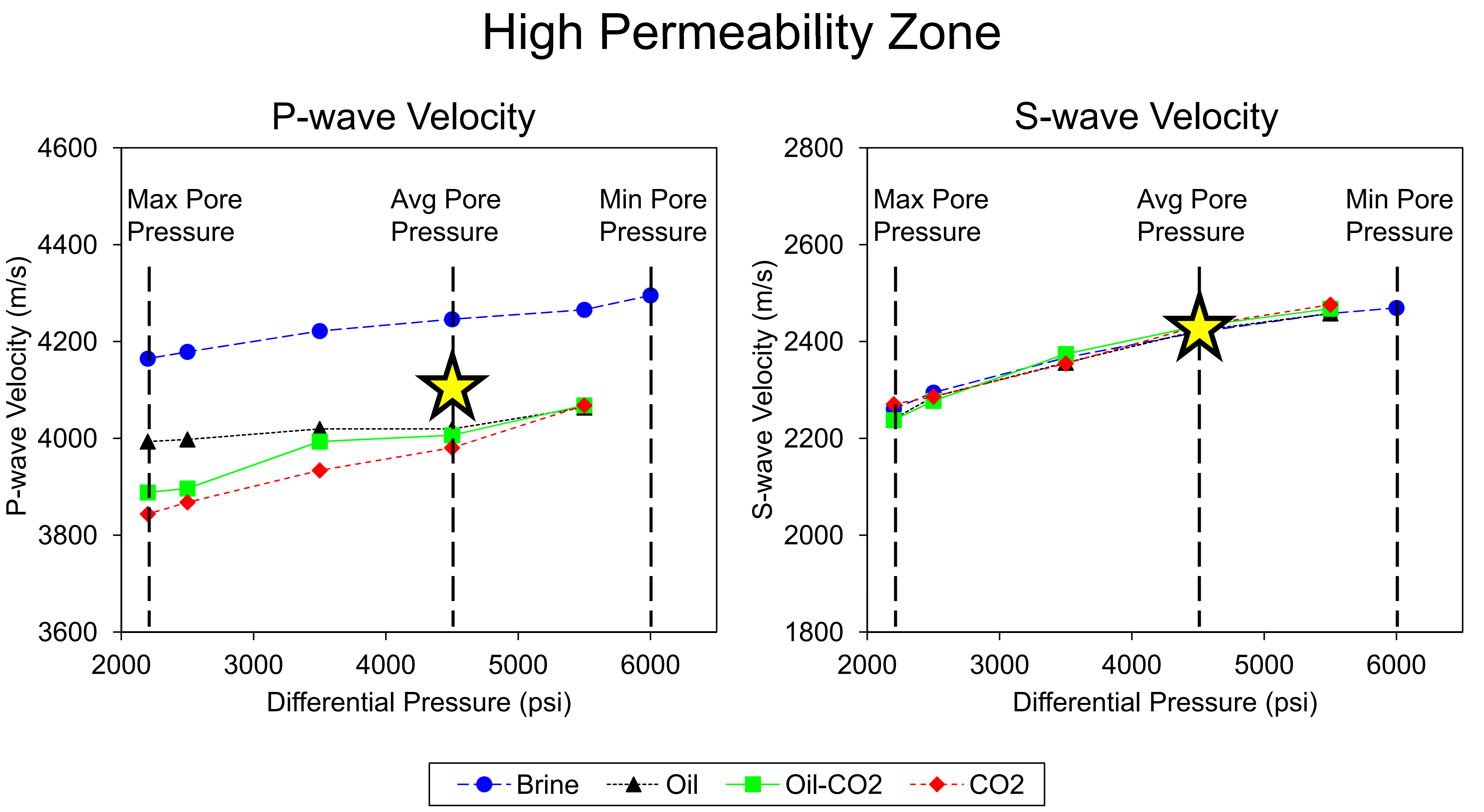
Laboratory Experiment

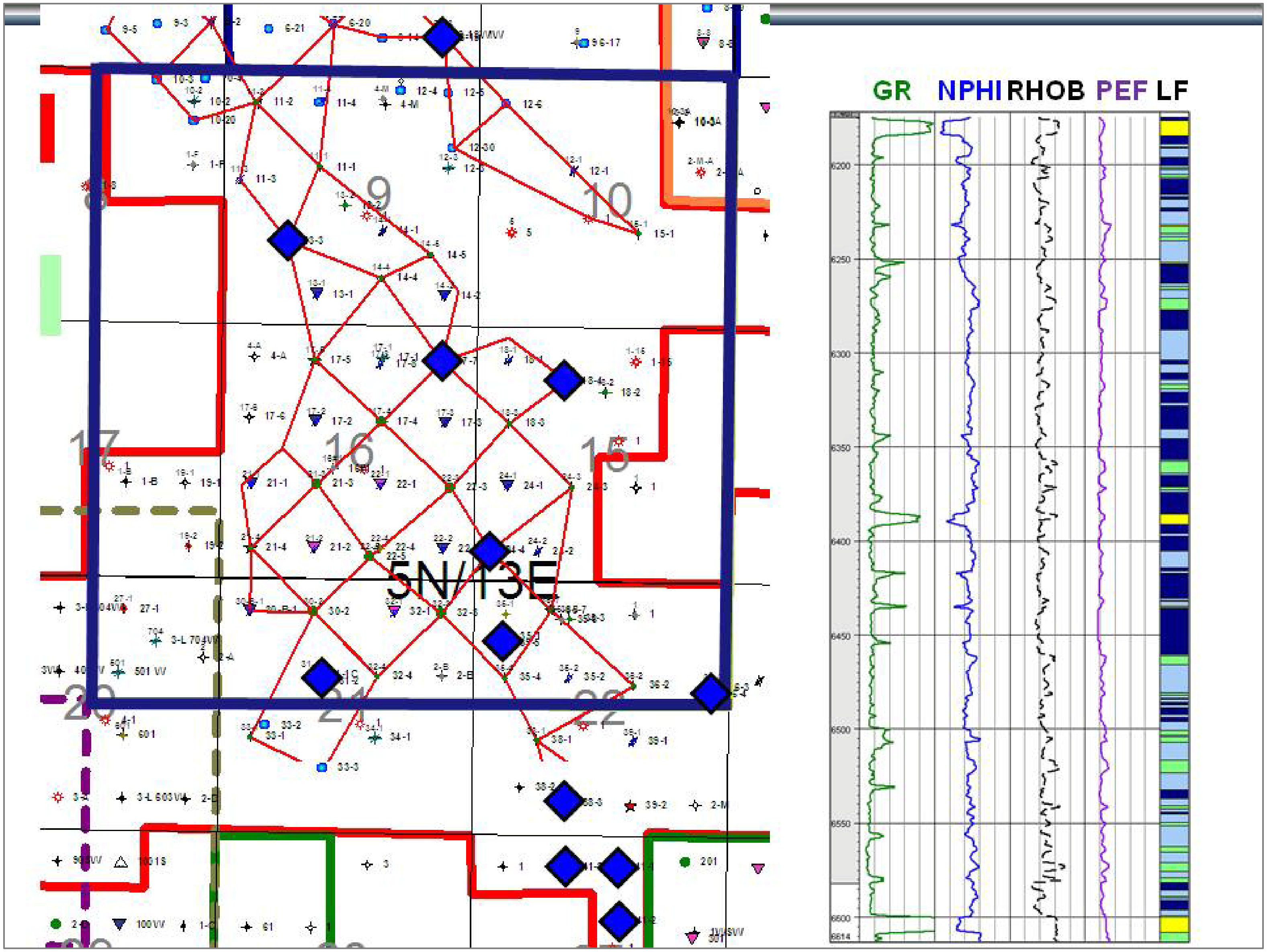
High Permeability Zone



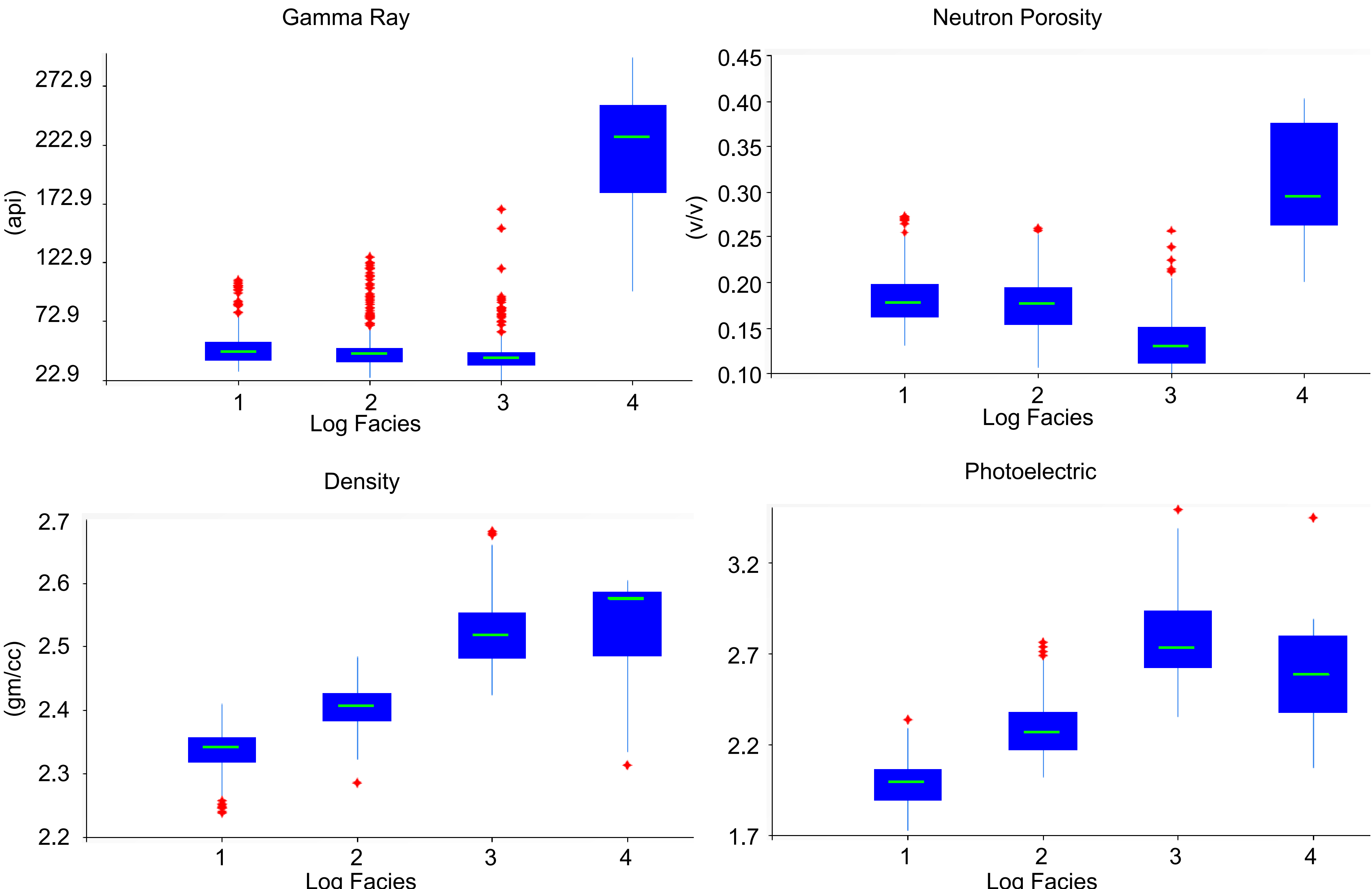
Presenter's Notes: How do we find the CO_2? What would the CO_2 look like? To answer these questions we need to understand the rock physics, petrophysics, etc.

Laboratory Experiment





Presenter's Notes: Since one of the objectives is to compare the log facies model with the wells that have core, I wanted to capture the variability within the reservoir. To do this I created a master well consisting of all the reservoir zones spliced together. I then tagged the wells with core to this Log Facies Model. (From the Heterogeneous Rock Analysis) we get our Log Facies model from the input curves Gamma Ray, Neutron Porosity, Bulk Density and Photoelectric Effect. The technique used to determine this Log Facies Model is principal component analysis to maximize the variability and cluster analysis to identify similar groupings of data. To understand what these Log Facies colors mean we can look at Box and Whisker Plots.

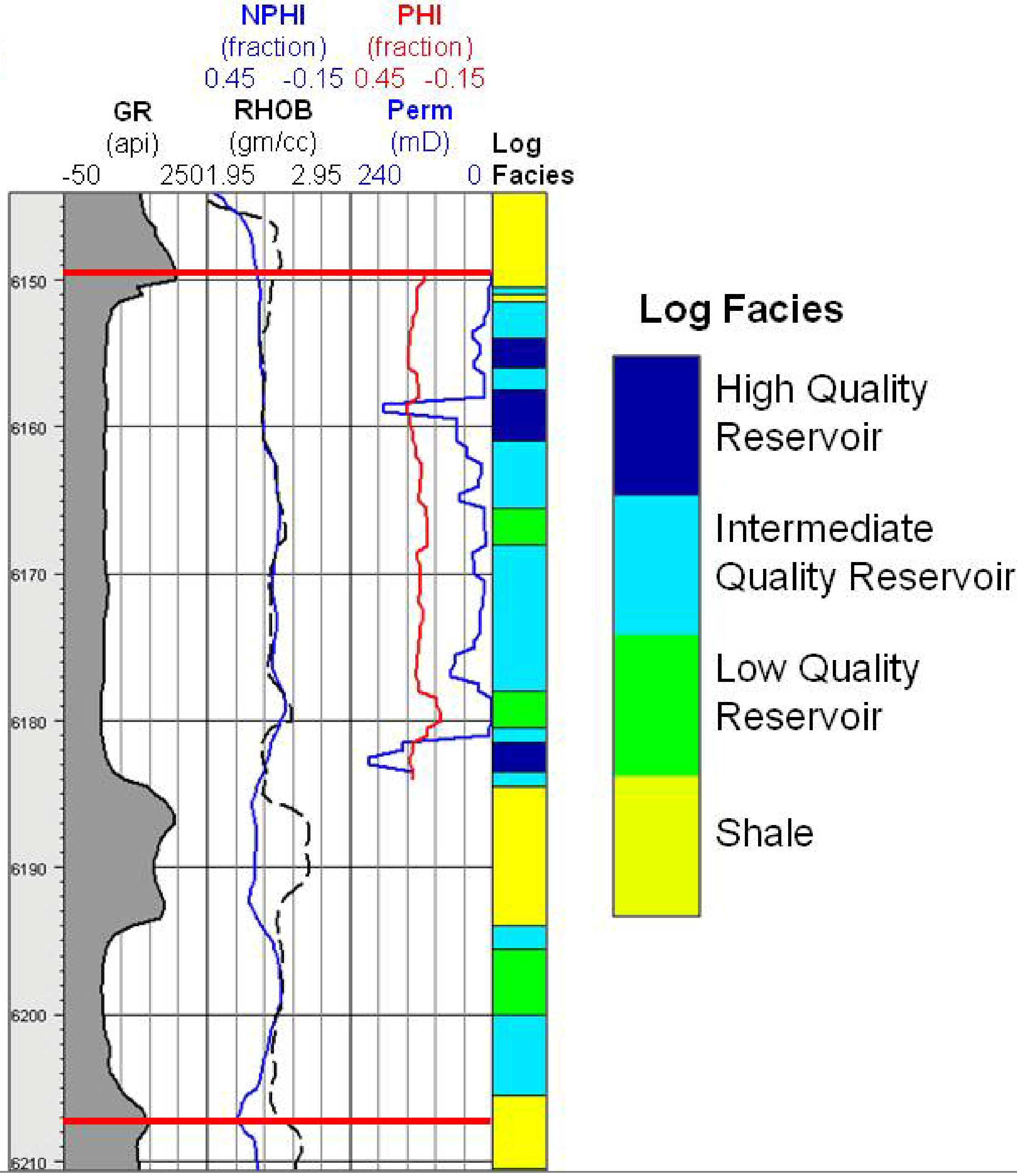


Log Facies

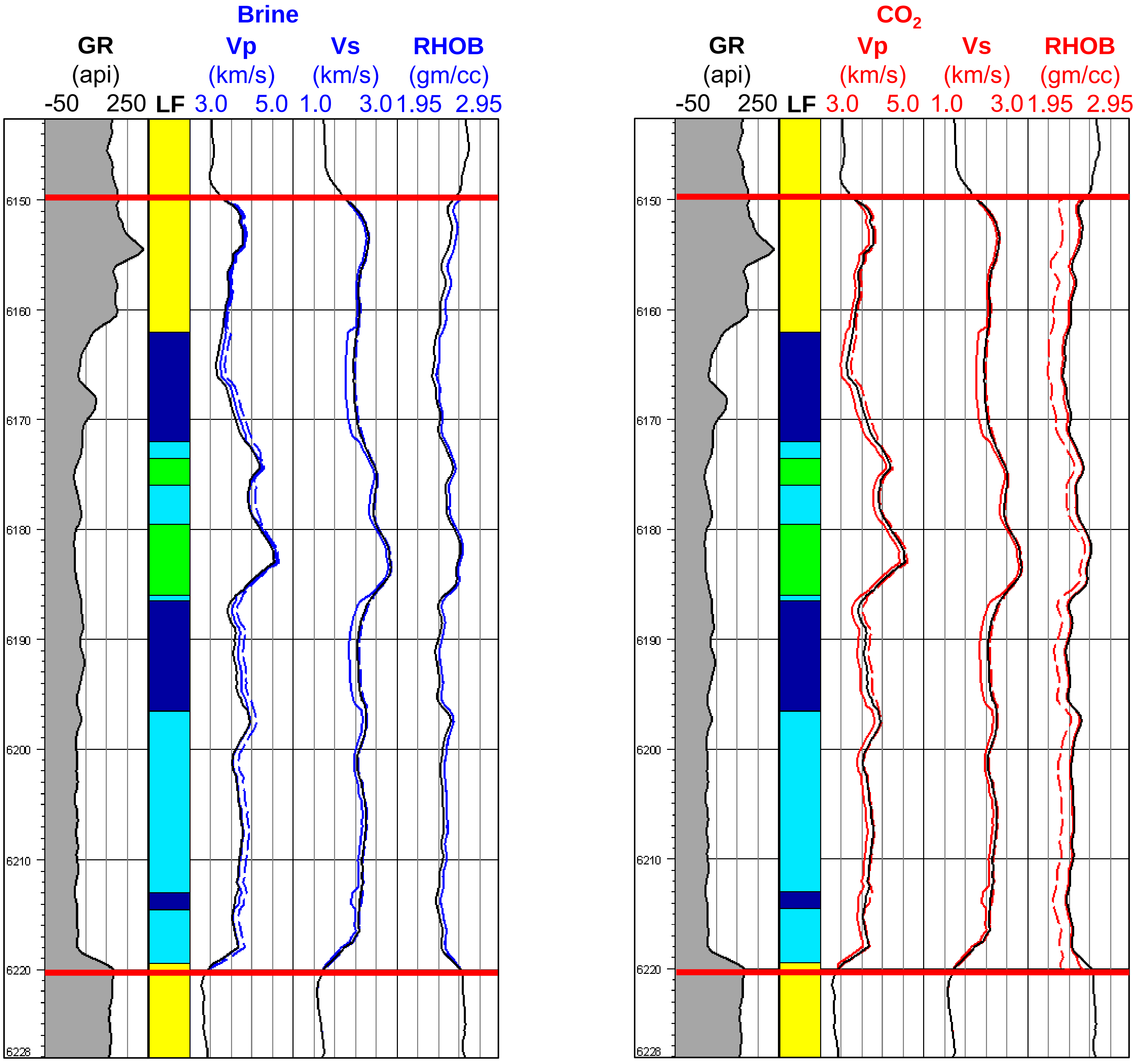
(1) High Quality Reservoir (2) Intermediate Quality Reservoir

(3) Low Quality Reservoir (4) Interbedded Shale

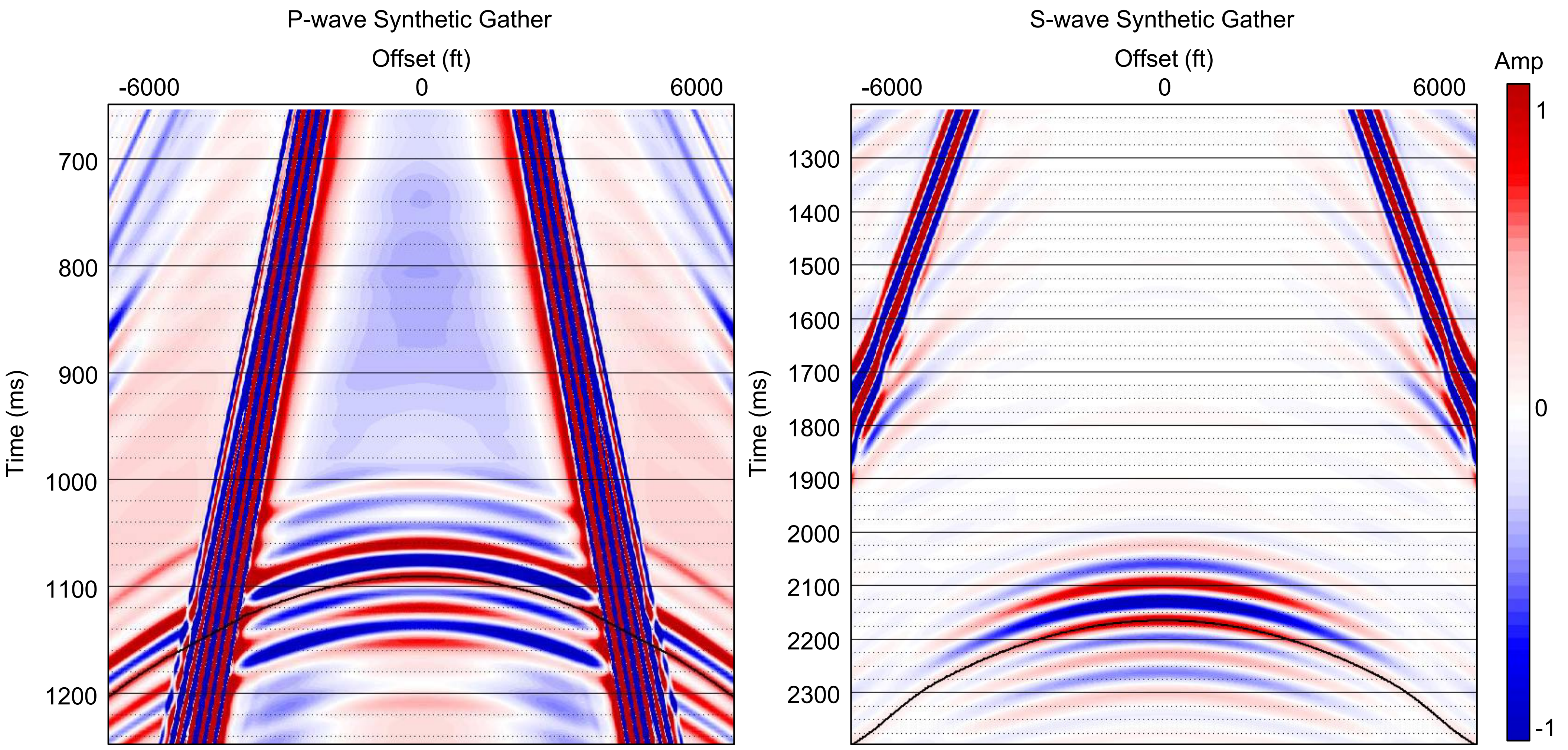
Log Facies Model



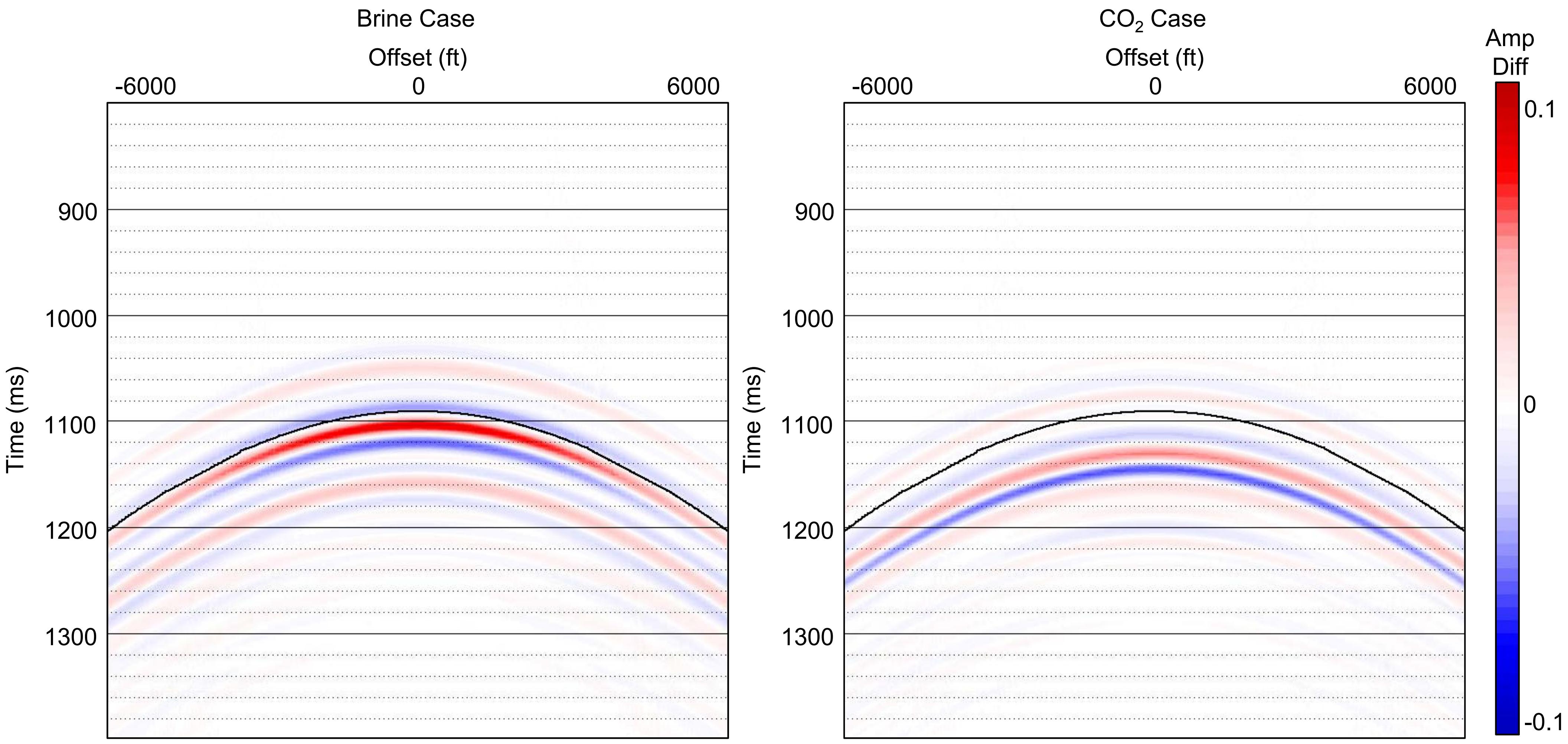
Presenter's Notes: The log facies model is then used to guide the changes in P- and S-wave velocity based on the observations made from the core experiments.


Brine
GR
(api)
-50 250
LF
Vp
(km/s)
3.0 5.0
Vs
(km/s)
1.0 3.0
RHOB
(gm/cc)
1.95 2.95
6150
6160
6170
6180
6190
6200
6210
6220
6228
CO_2
GR
(api)
-50 250
LF
Vp
(km/s)
3.0 5.0
Vs
(km/s)
1.0 3.0
RHOB
(gm/cc)
1.95 2.95
6150
6160
6170
6180
6190
6200
6210
6220
6228

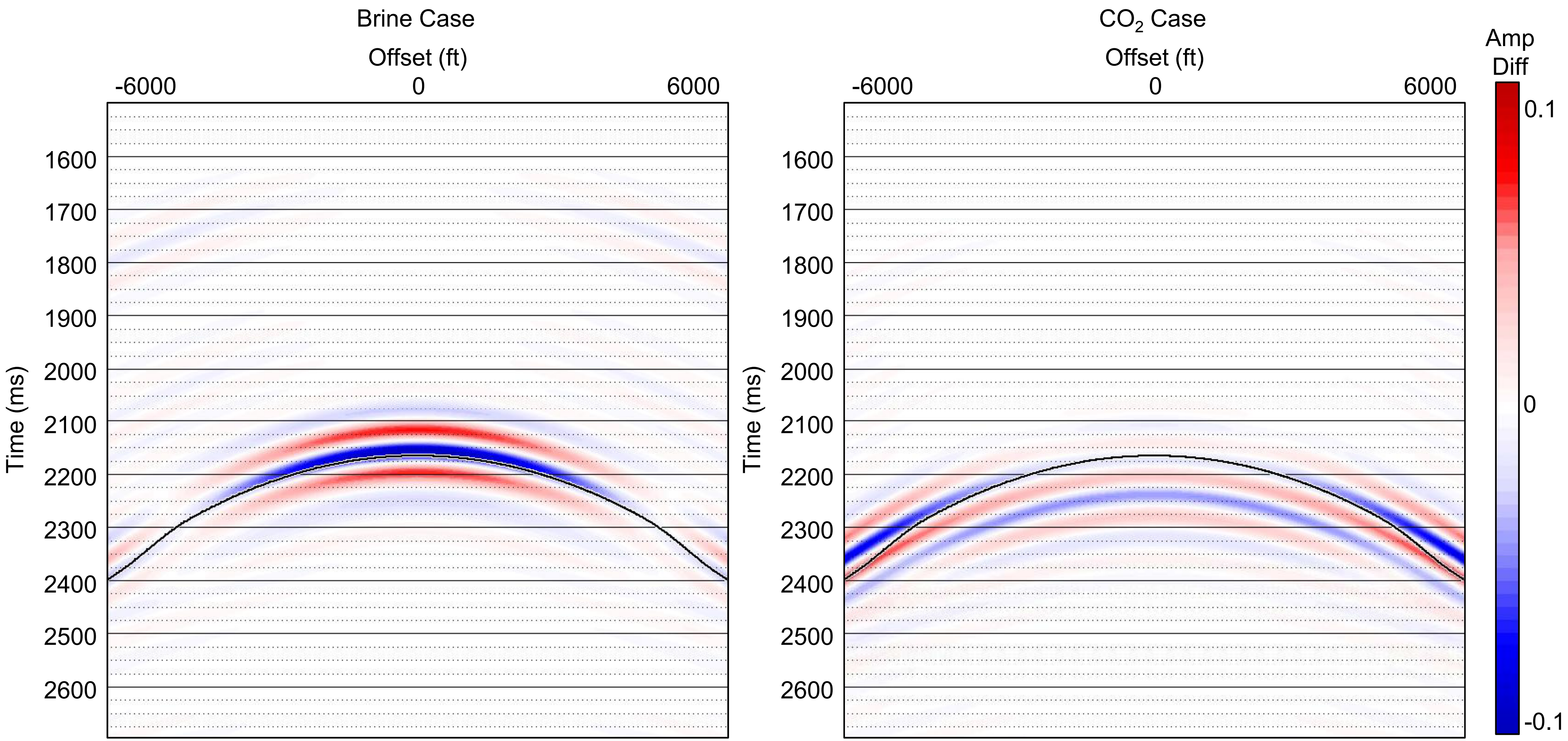
Full Waveform Seismic Modeling



P-wave Amplitude Difference



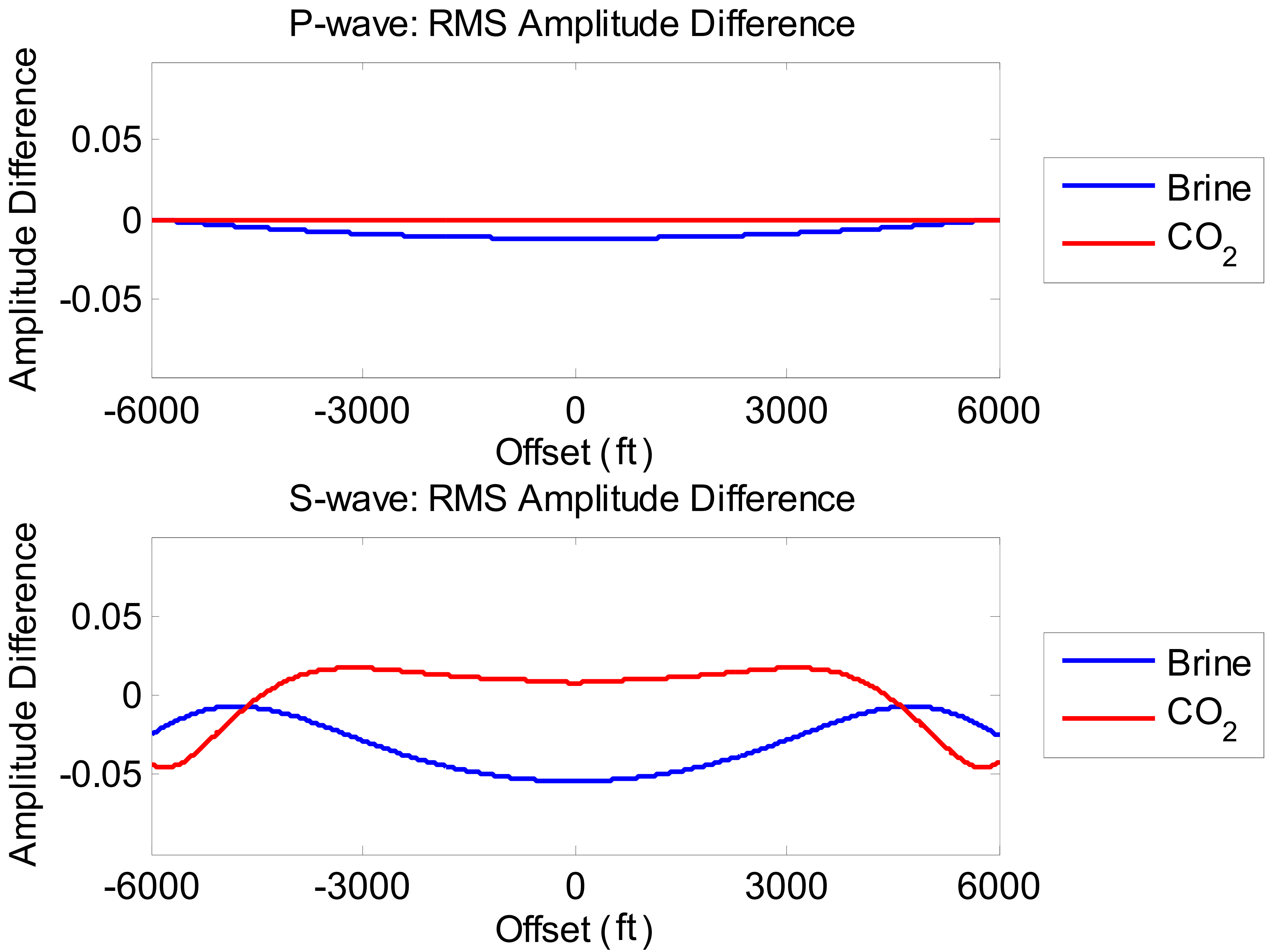
S-wave Amplitude Difference



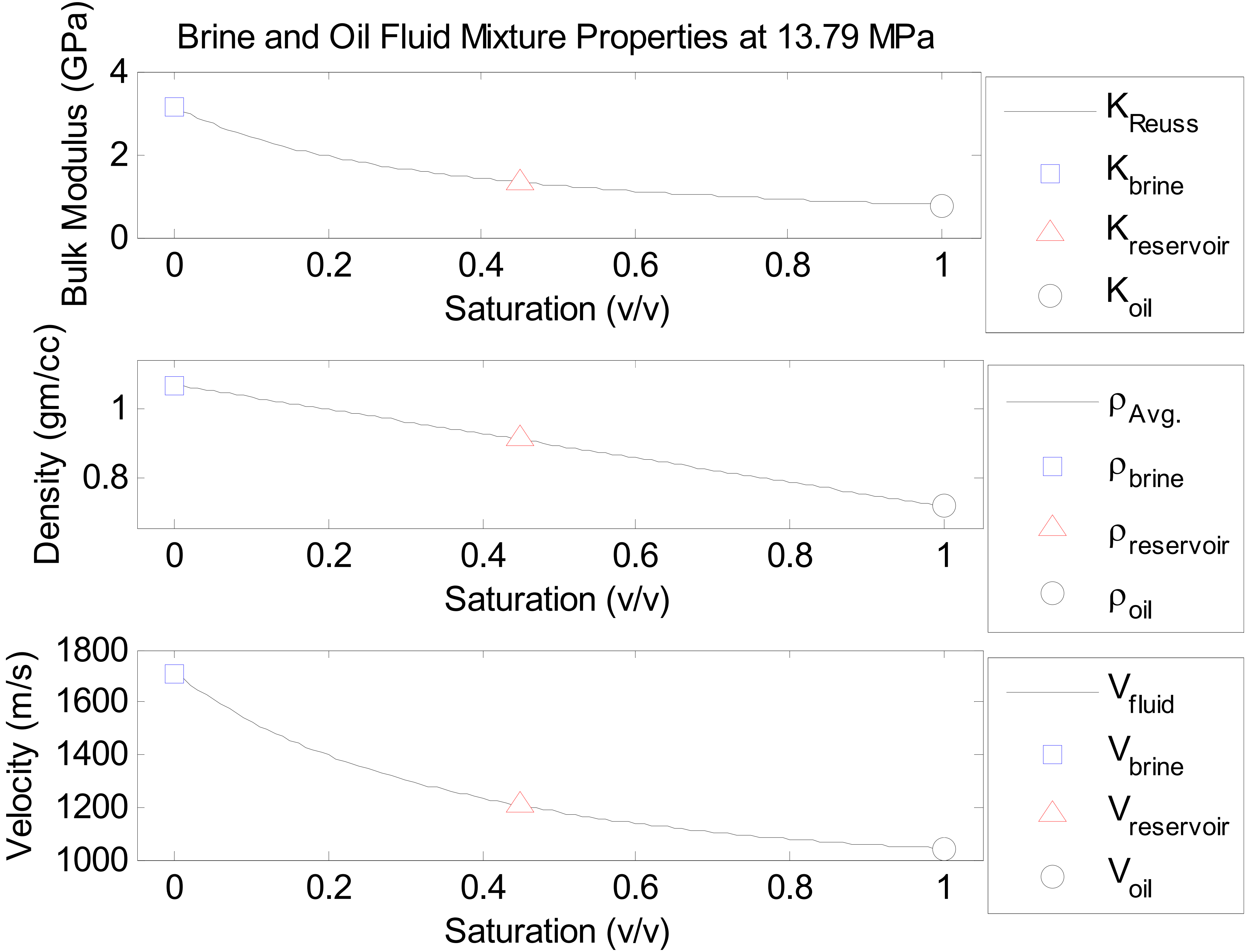
Summary

- High permeability samples most stress sensitive
- Challenges modeling laboratory data
- Log Facies Model identifies different permeability zones
- Seismic modeling shows different amplitude responses for the brine and CO_2 cases
- Motivation for combining P- and S-wave attributes to improve time-lapse studies
- Motivation for a time-lapse study on angle stacks

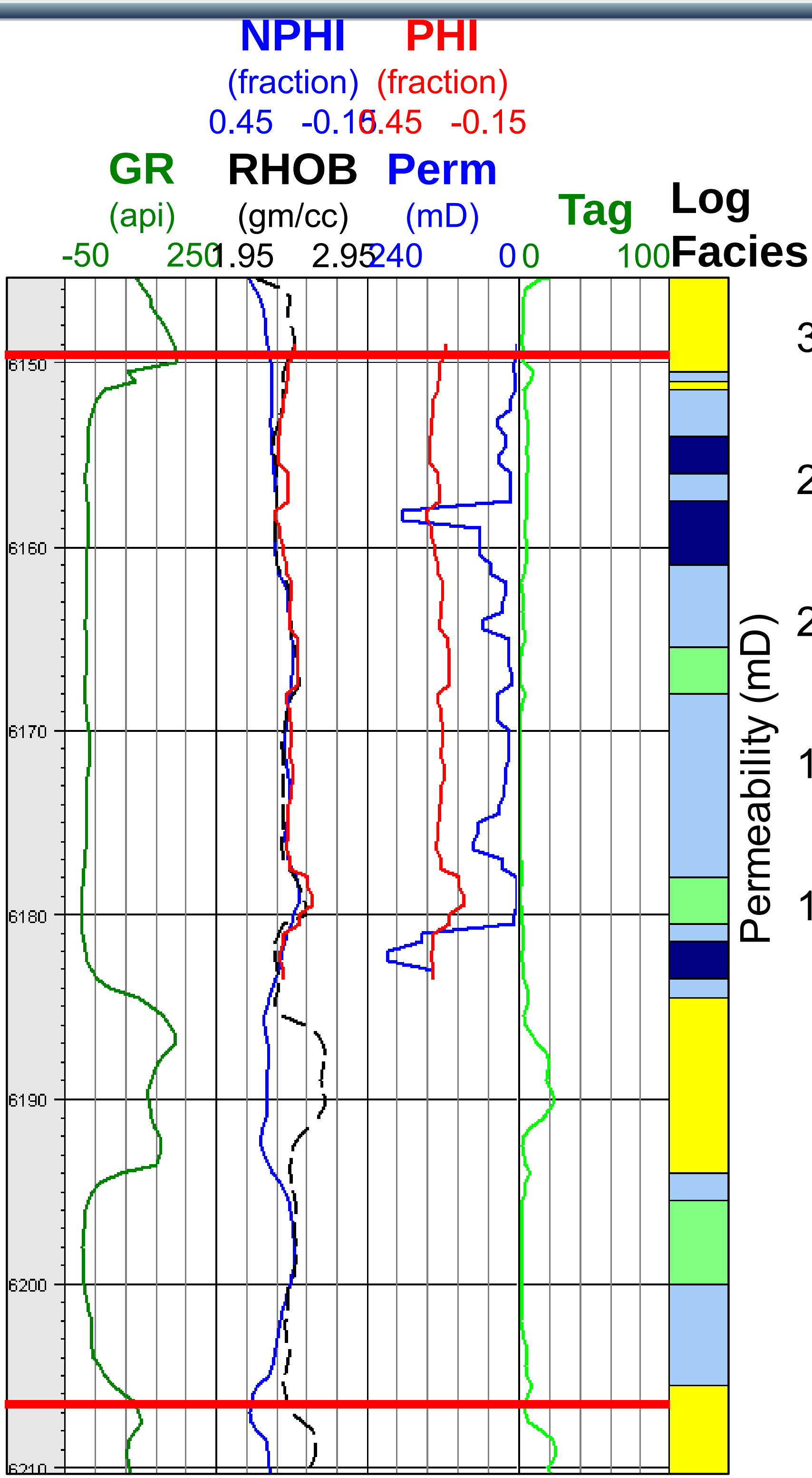
THANK YOU

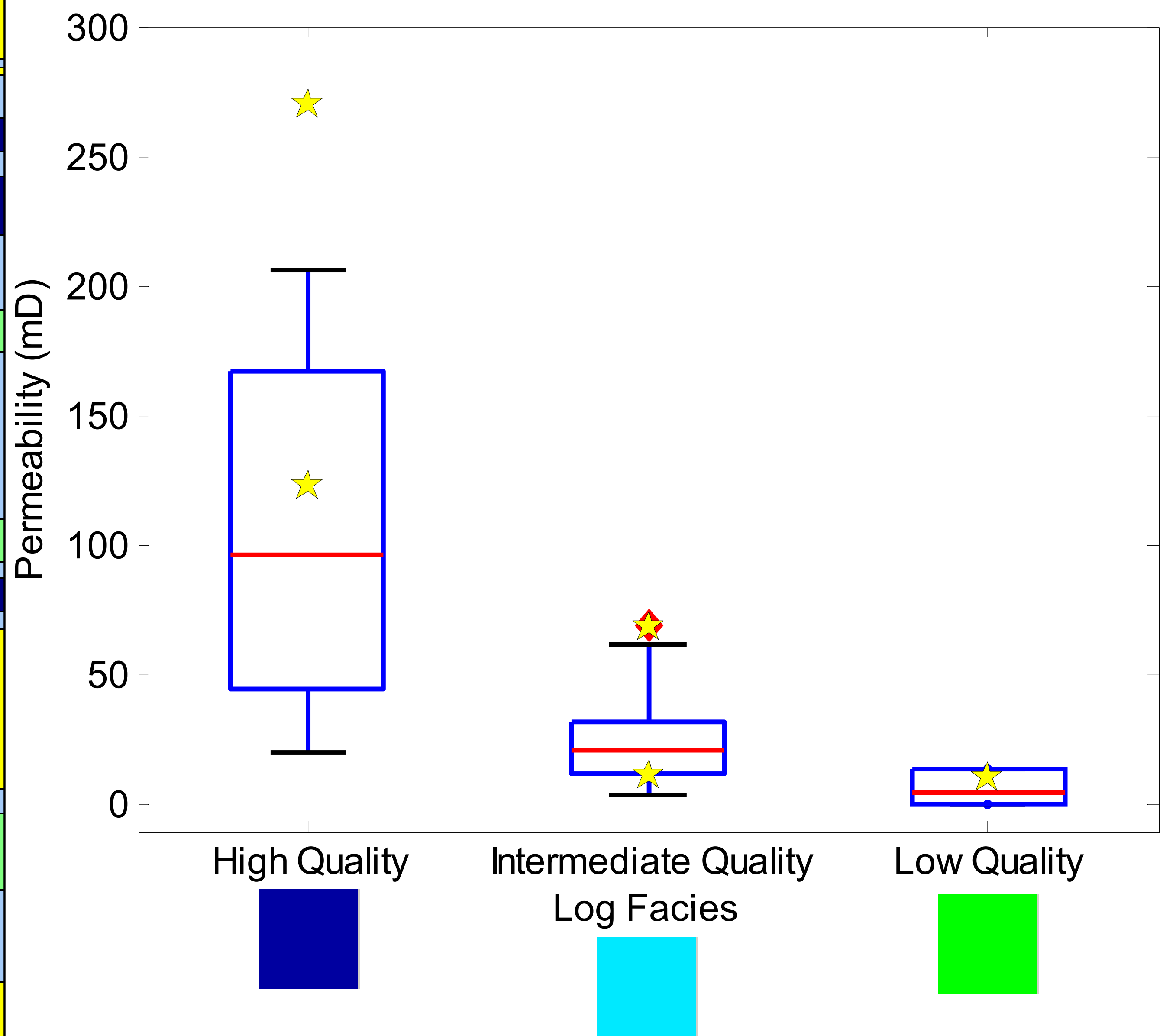


P-wave: RMS Amplitude Difference
Amplitude Difference
0.05
0
-0.05
-6000
-3000
0
3000
6000
Offset (ft)
Brine
CO2
S-wave: RMS Amplitude Difference
Amplitude Difference
0.05
0
-0.05
-6000
-3000
0
3000
6000
Offset (ft)
Brine
CO2

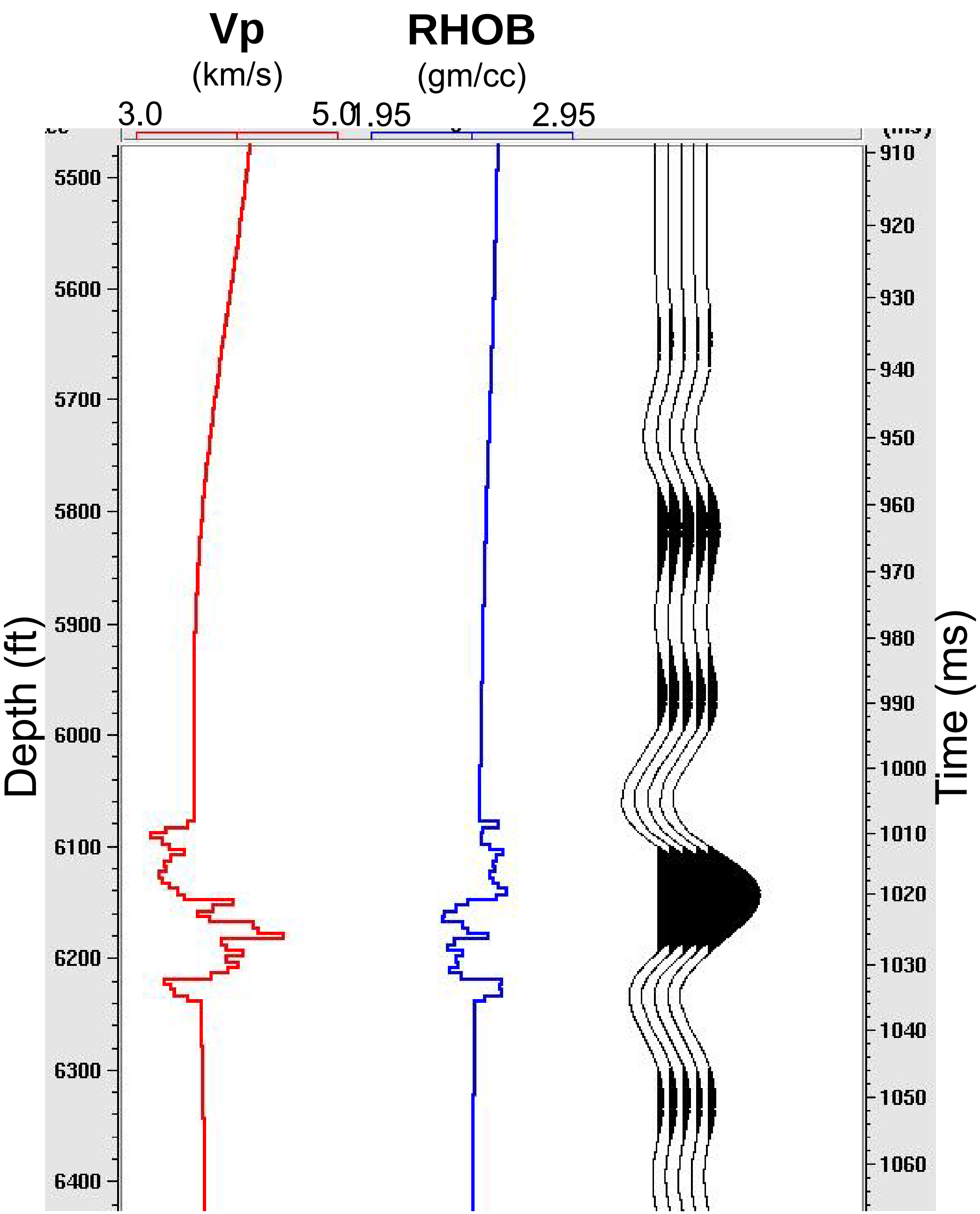

Brine and Oil Fluid Mixture Properties at 13.79 MPa
Bulk Modulus (GPa)
4
2
0
0
0.2
0.4
0.6
0.8
1
Saturation (v/v)
K_Reuss
K_brine
K_reservoir
K_oil
Density (gm/cc)
1
0.8
0
0.2
0.4
0.6
0.8
1
Saturation (v/v)
ρ_Avg.
ρ_brine
ρ_reservoir
ρ_oil
Velocity (m/s)
1800
1600
1400
1200
1000
0
0.2
0.4
0.6
0.8
1
Saturation (v/v)
V_fluid
V_brine
V_reservoir
V_oil

Log Facies Model

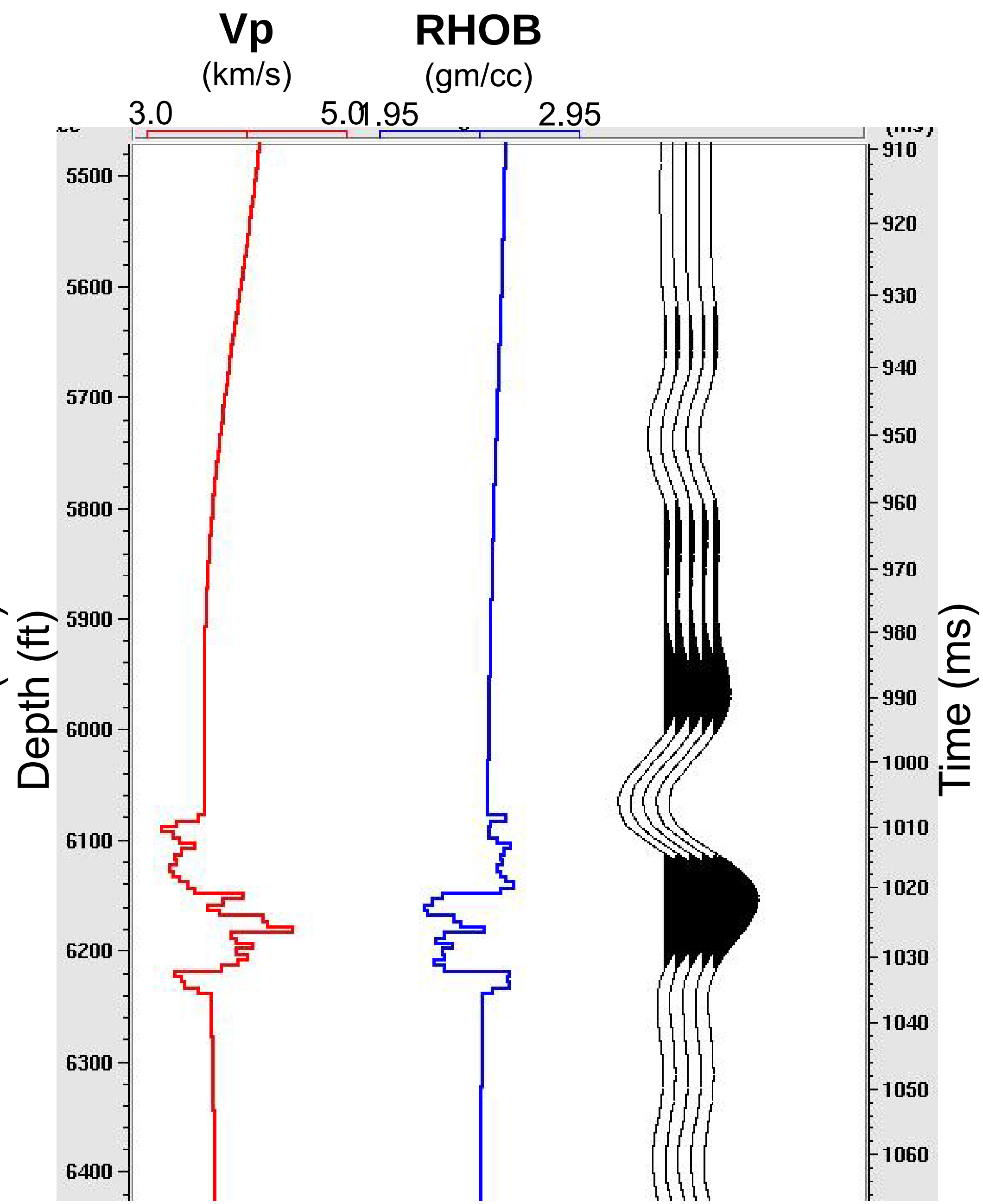




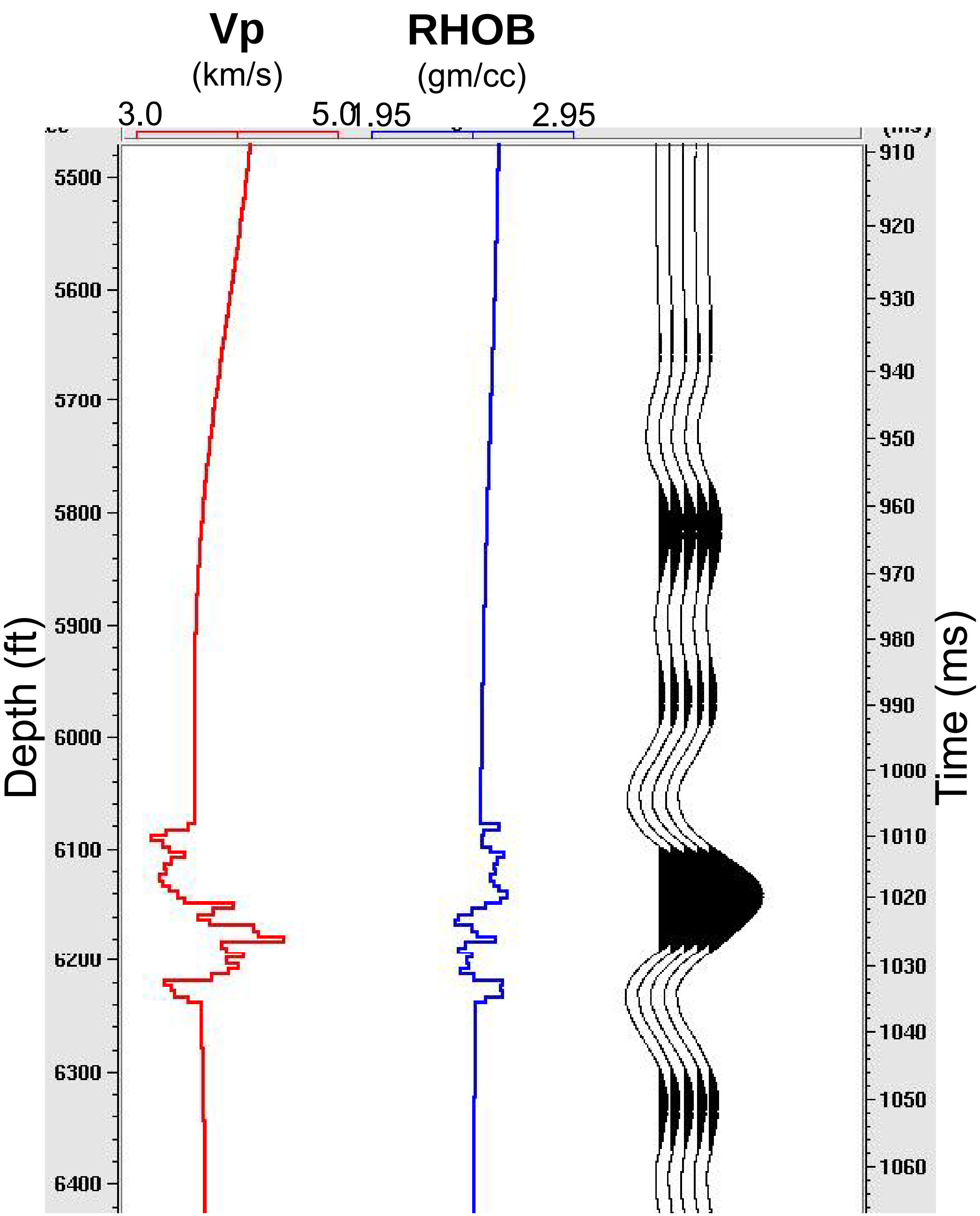
CO_2 Case Pp:4300 psi



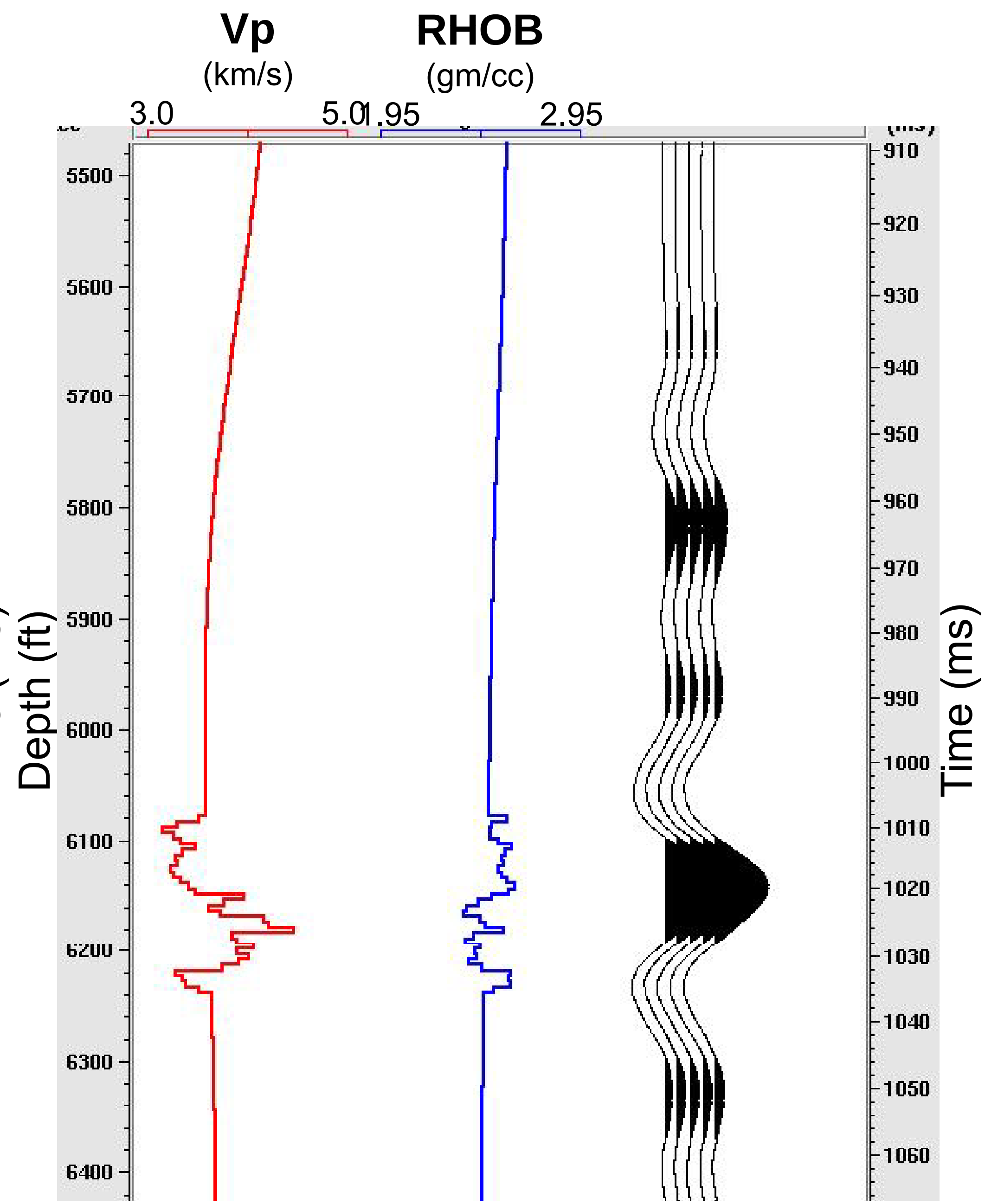
CO_2 Case Pp:1000 psi



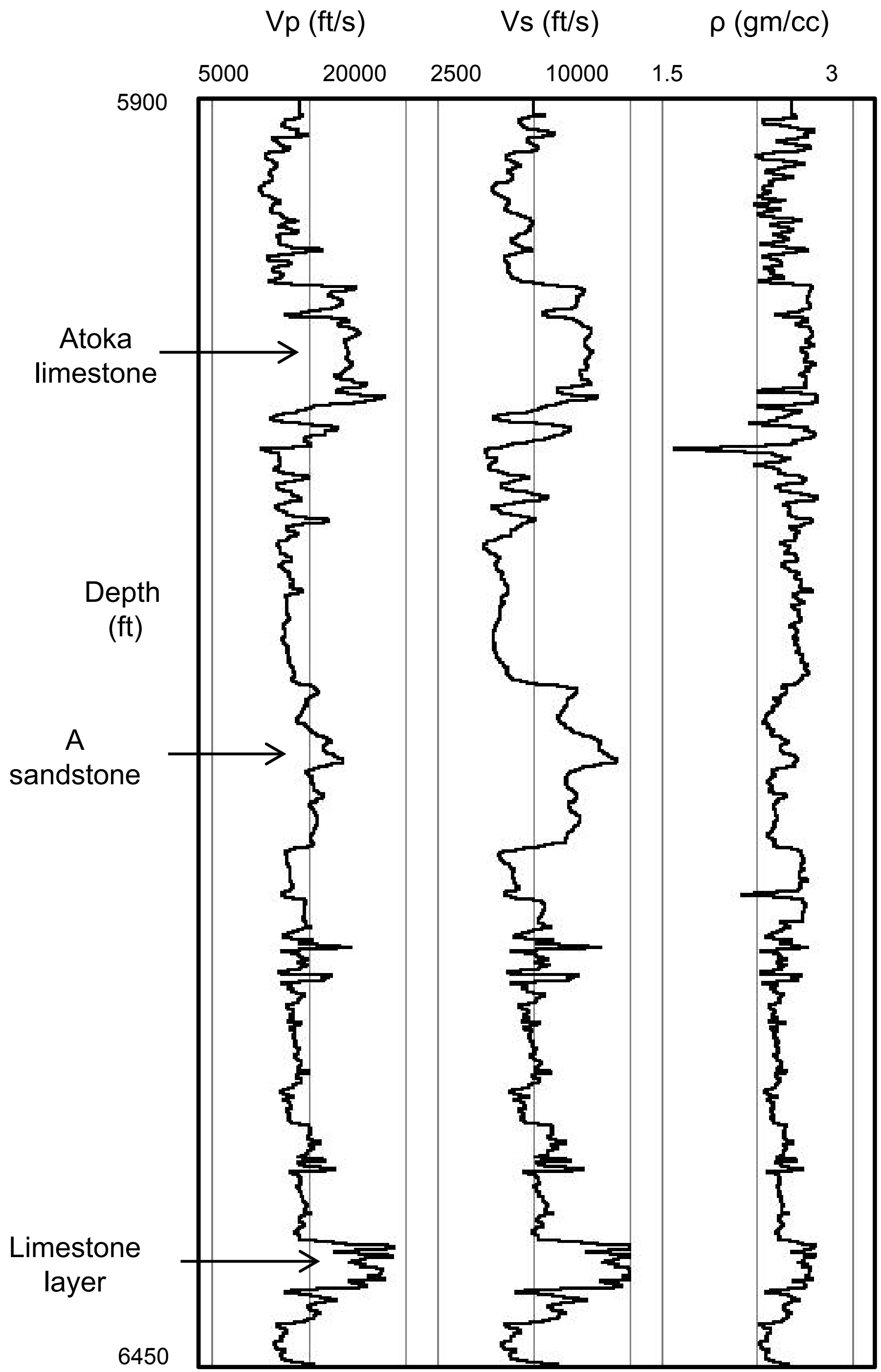
Brine Case Pp:4300 psi



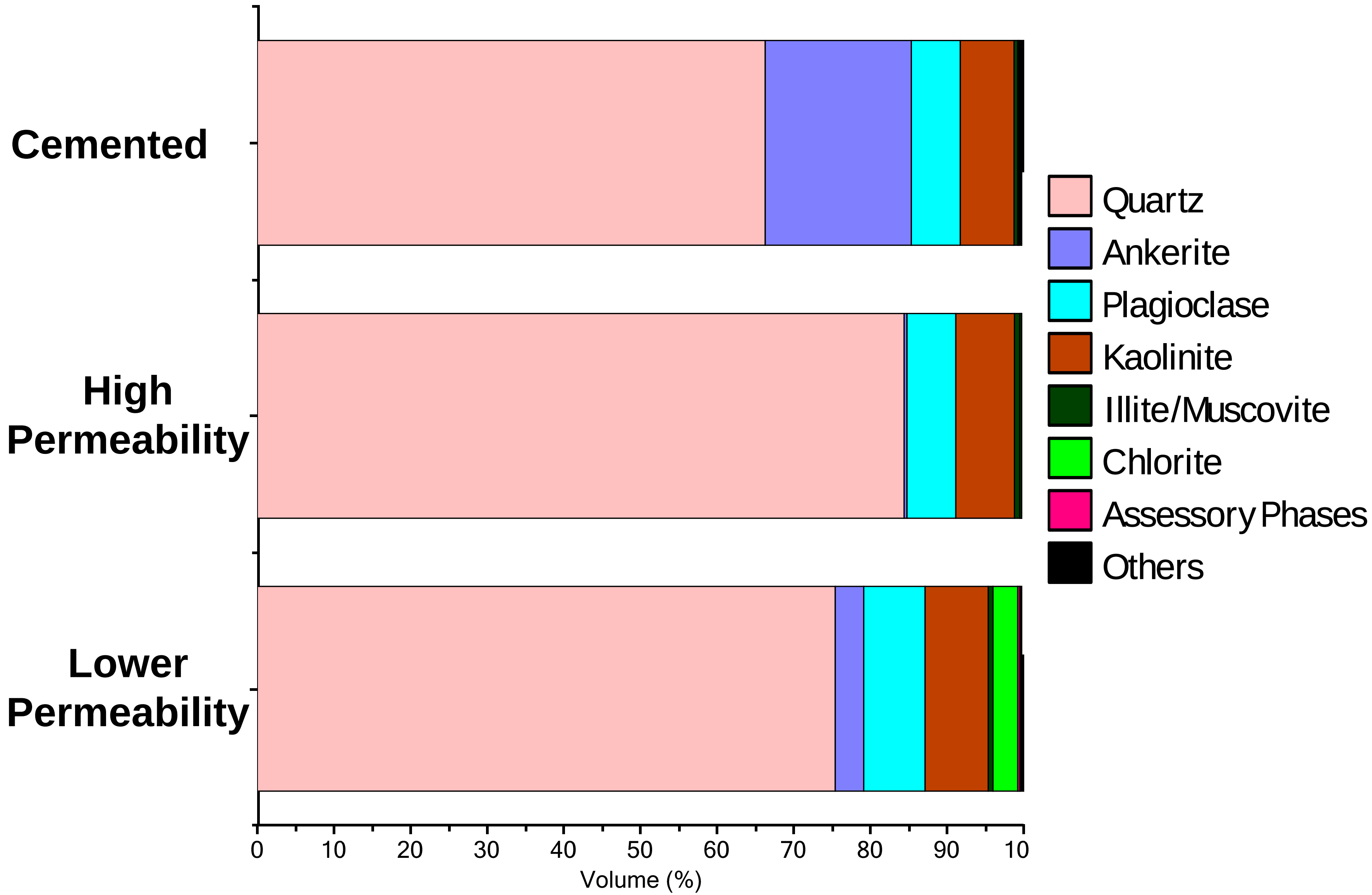
Brine Case Pp:1000 psi



Sandstone model building



Singh and Davis, 2010


Cemented
High Permeability
Lower Permeability
0
10
20
30
40
50
60
70
80
90
10
Volume (%)
Quartz
Ankerite
Plagioclase
Kaolinite
Illite/Muscovite
Chlorite
Assessory Phases
Others