Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Geologic – Monitoring, Mitigation, and Verification (2)

Feasibility of seismic monitoring of CO_2 sequestration in the deep formations in the Ohio River Valley Region

Haibin Xu*, Ben Flack, Richard Salter, and Randal Utech, WesternGeco
Neeraj Gupta, Battelle Memorial Institute
T. S. Ramakrishnan and Austin Boyd, Schlumberger-Doll Research

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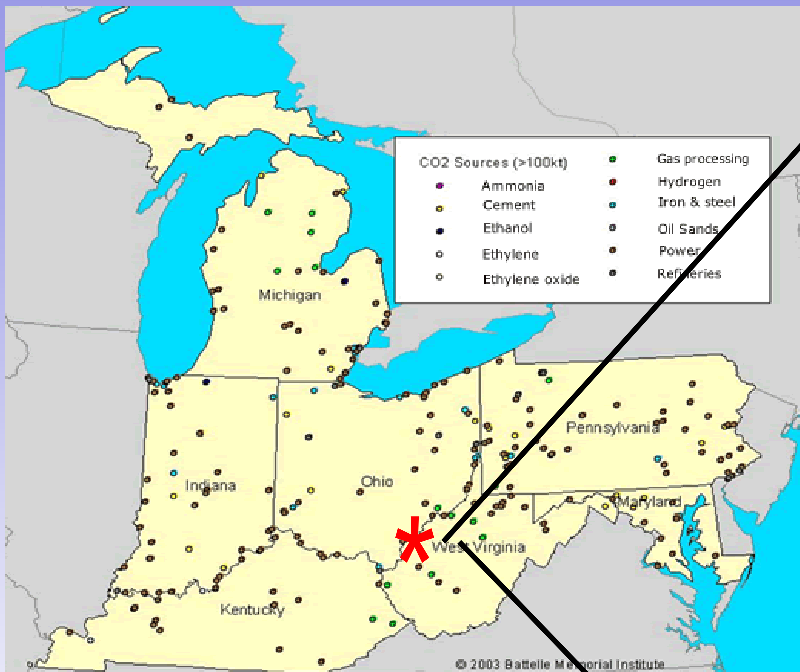
Ohio Coal Development Office

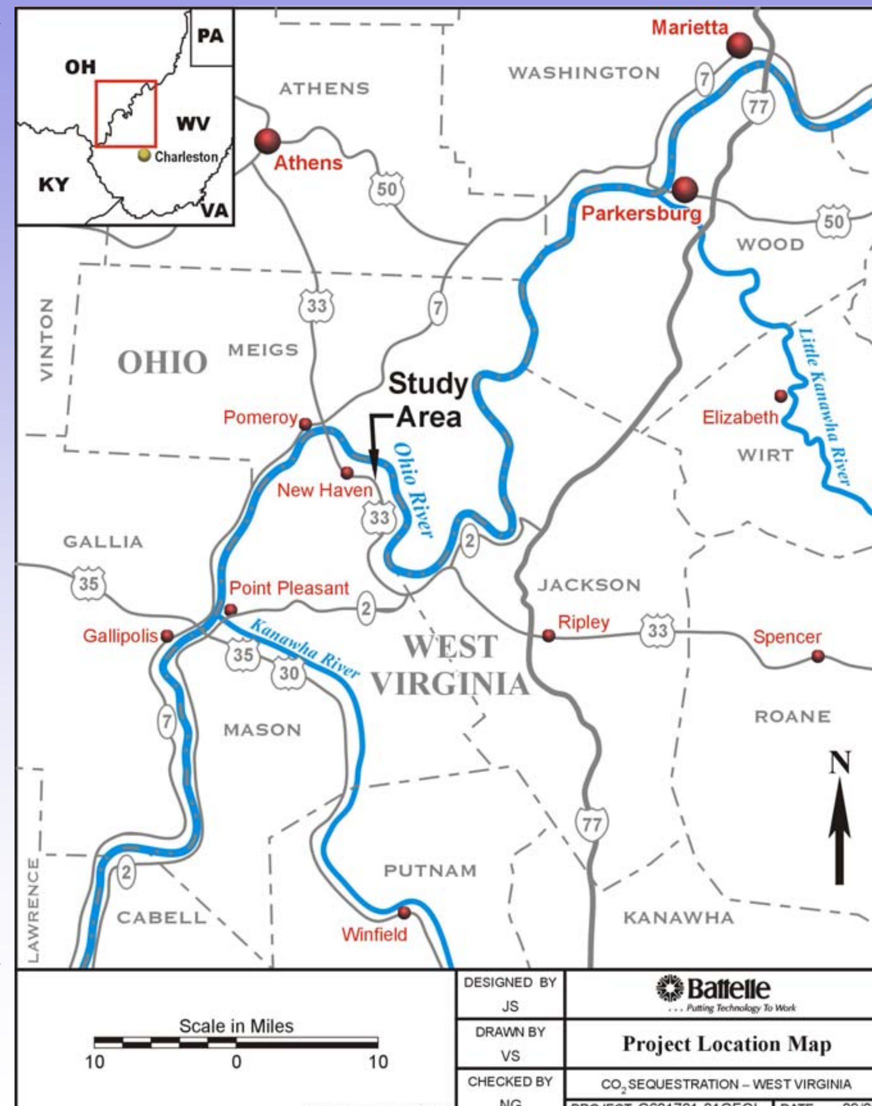
Outline

- Introduction
- CO_2 acoustic properties calculation
- AEP-1 well (Appalachian Basin) feasibility study
- Ohio River Valley regional analogs
- Conclusions

Project location



Mountaineer Power plant (AEP-1 well)



Objective of site-characterization project

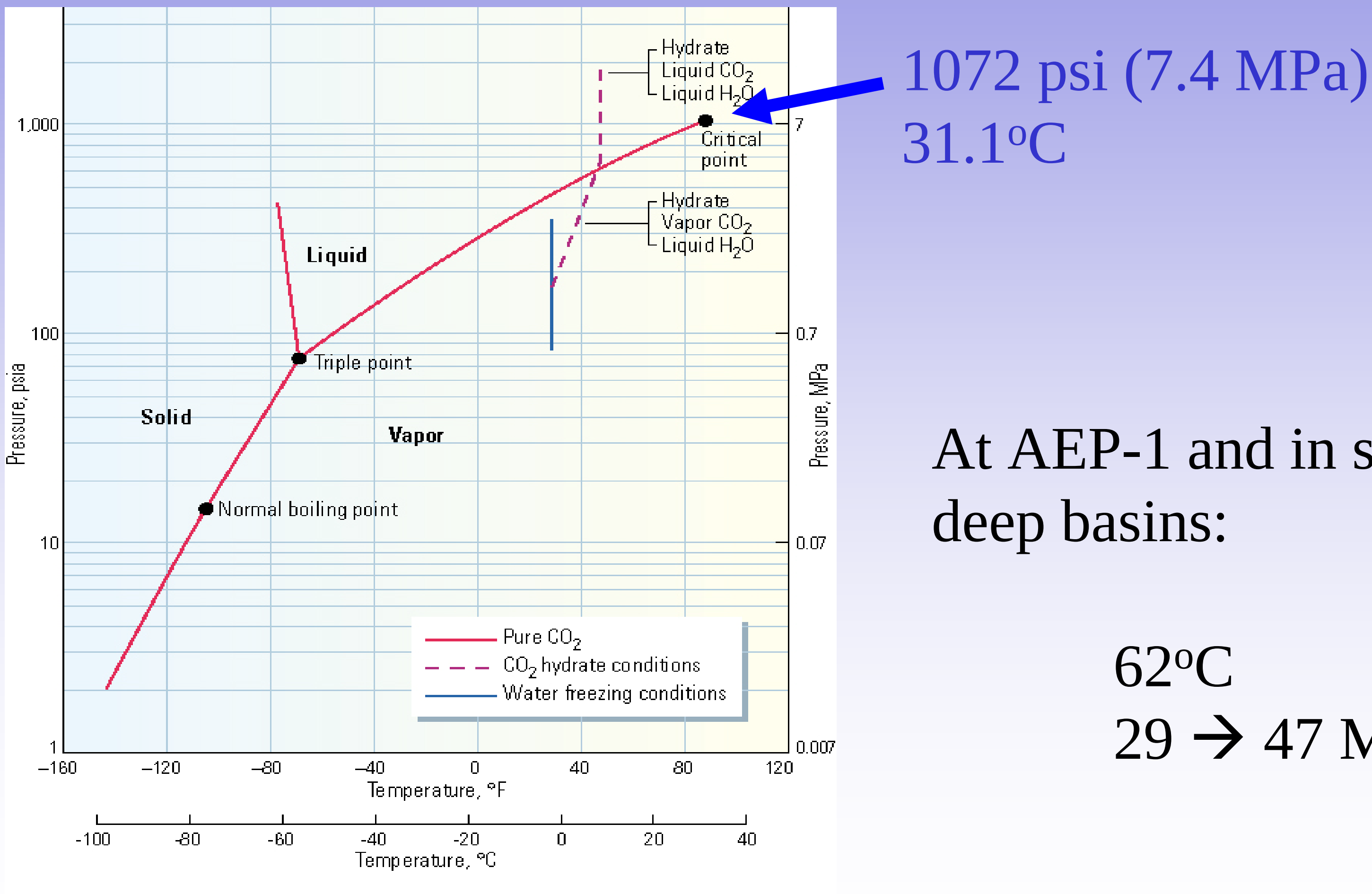
- Feasibility of seismic monitoring in the Appalachian Basin area
  - Data available: AEP-1 well location
    - Two 2D seismic lines
    - Wireline logs + core data
    - Regional geologic studies
- Feasibility of seismic monitoring in the Ohio River Valley Region

Key questions of a feasibility study

- What is our ability in predicting the expected 4D signature?
  - How valid is *Gassmann Equation* for the specific reservoir-rock?
  - How accurate are the input parameters into Gassmann?
    - Petrophysical data
    - Fluid properties estimation from *Batzle-Wang Equations*

- How well can a seismic survey & subsequent data interpretation pick up the 4D signature?

Acoustic properties of CO_2



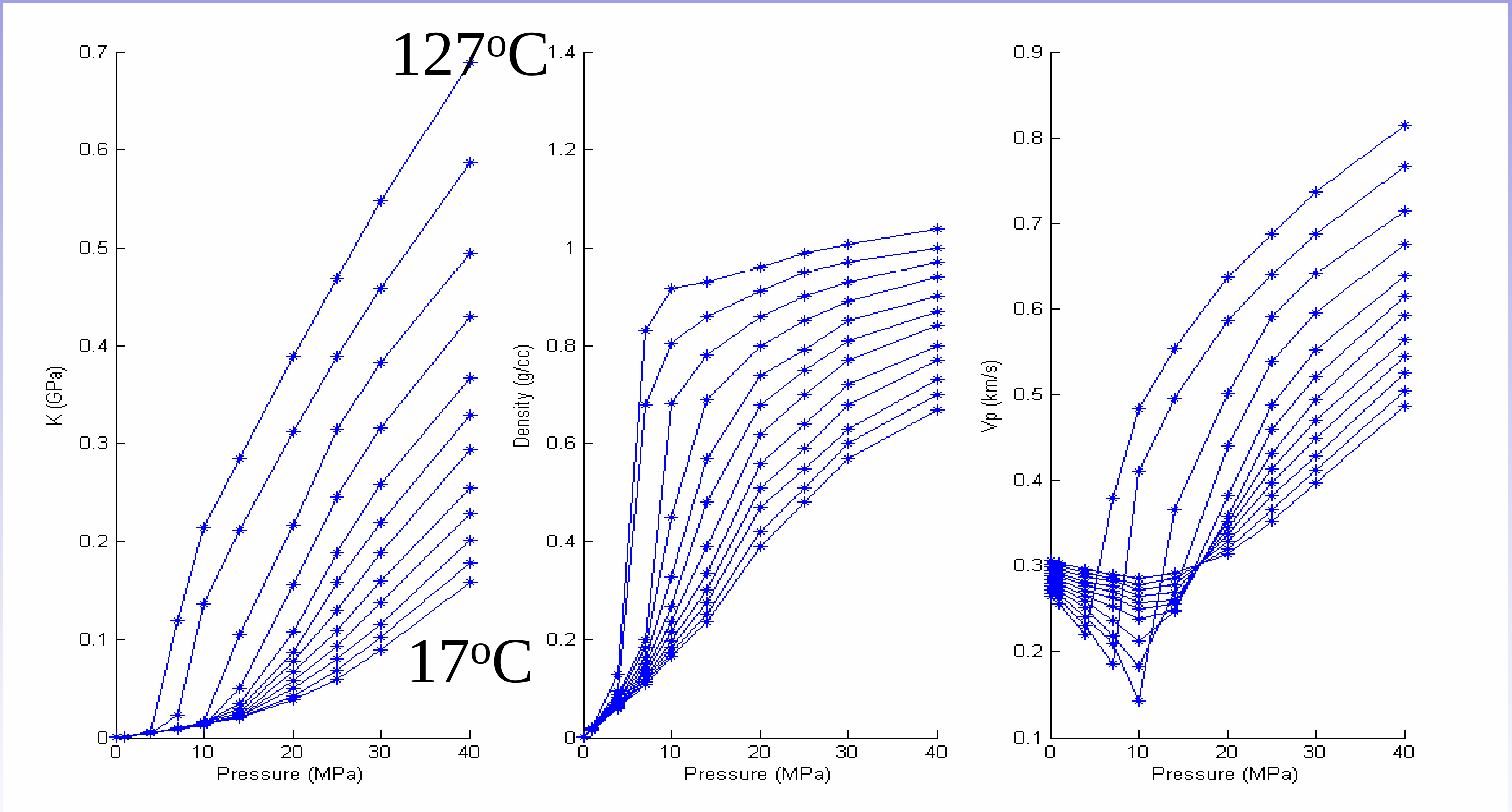
From Bennaceur et al., 2004

At AEP-1 and in similar deep basins:

62°C

29 → 47 MPa

Laboratory measurements (Wang, 1989)



At AEP-1 and other deep basins:

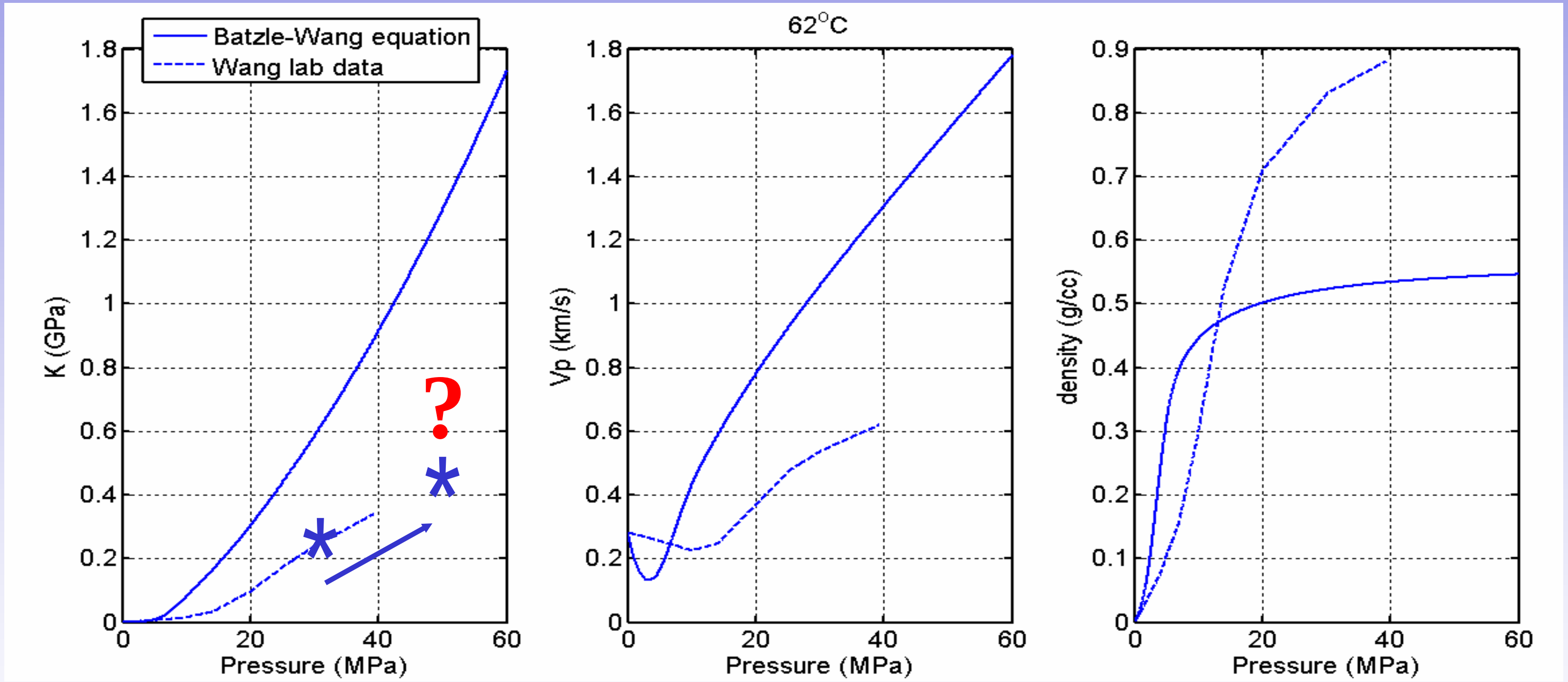
62°C

29 → 47 MPa

Batzle-Wang equations

- In the seismic world, Batzle-Wang (1992) is the de-facto standard equations for computing fluid velocities
  - Default in most commercial packages
- Inputs
  - Temperature, pressure, gas gravity, oil API
  - For example, gas gravity of CO_2 is 1.53 = 1.98/1.29
    - Density of CO_2 : 1.98 g/L at standard condition
    - Density of air: 1.29g/L at standard condition
- Outputs
  - Velocity and density of gas & oil

Batzle-Wang equations: applicability to CO_2



CO2 injection

At AEP-1 or other deep basins:

62°C

29 → 47 MPa

Why the discrepancy?

Important built-in assumption:

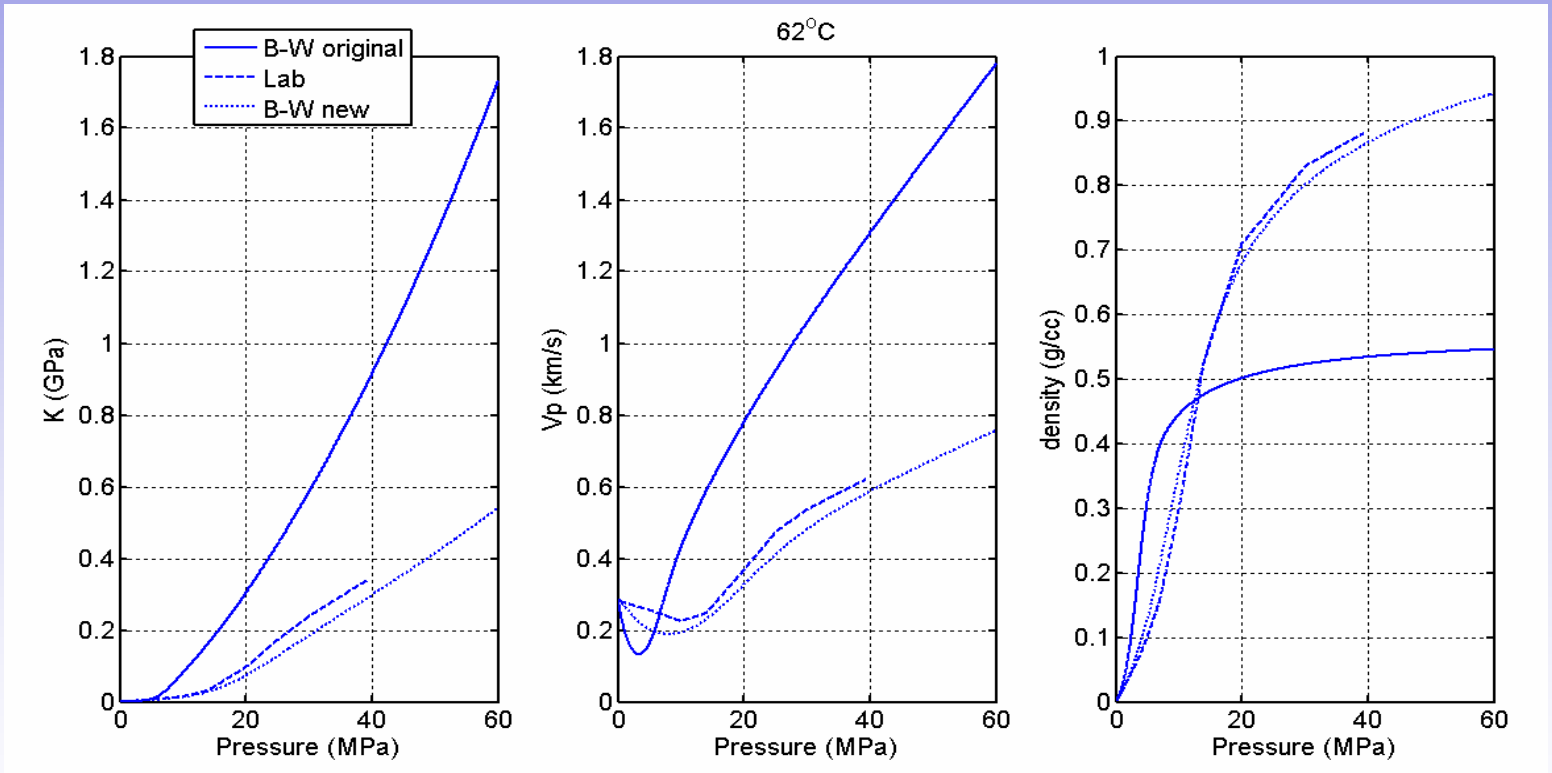
$$P_{pc} = 4.892 - 0.4048\,\rho_g$$

7.4 MPa 4.3 MPa 1.53

$$T_{pc} = 94.72 + 170.75\,\rho_g$$

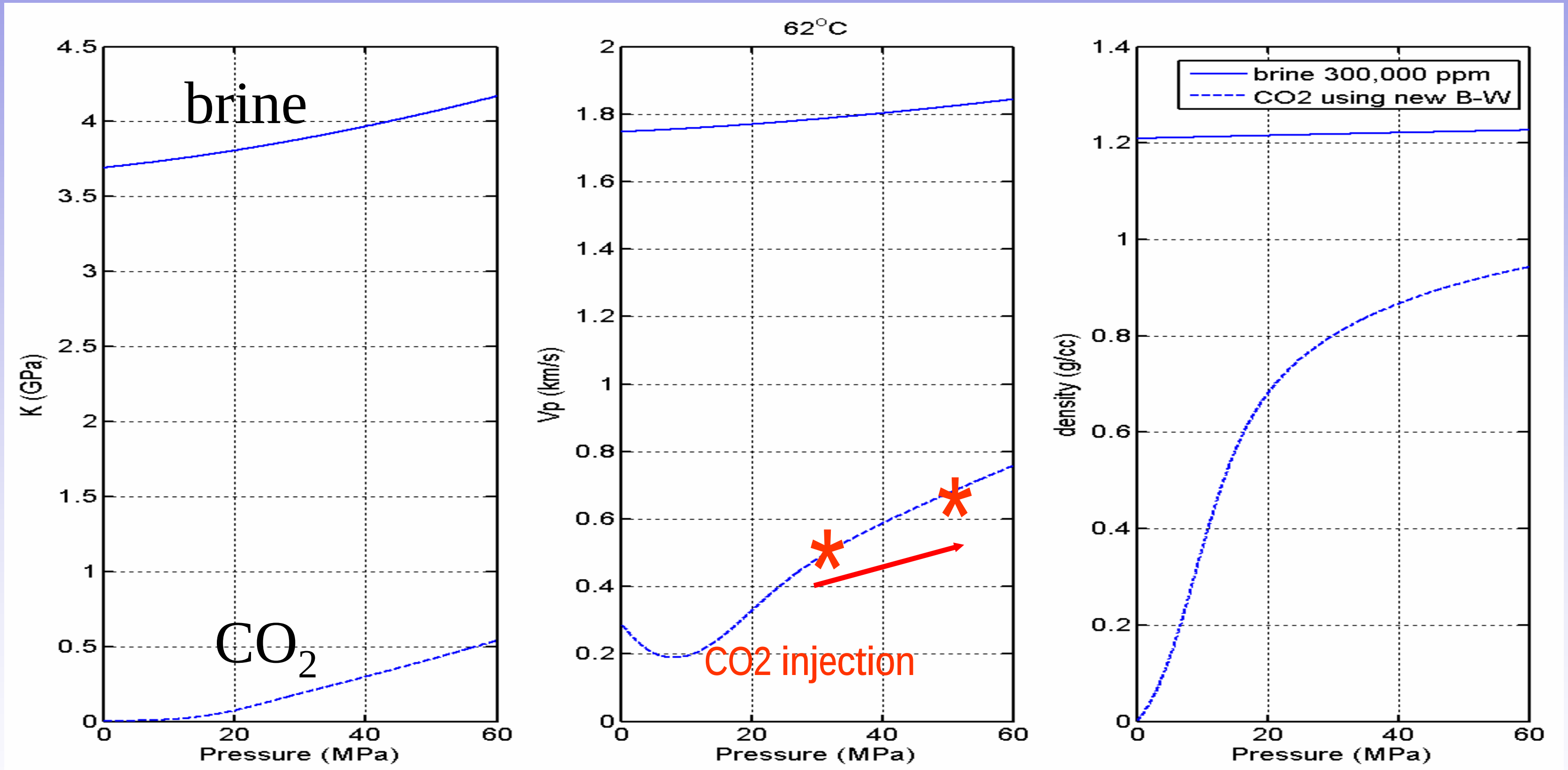
31.1^{o}C 83.7^{o}C 1.53

Modified Batzle-Wang equation

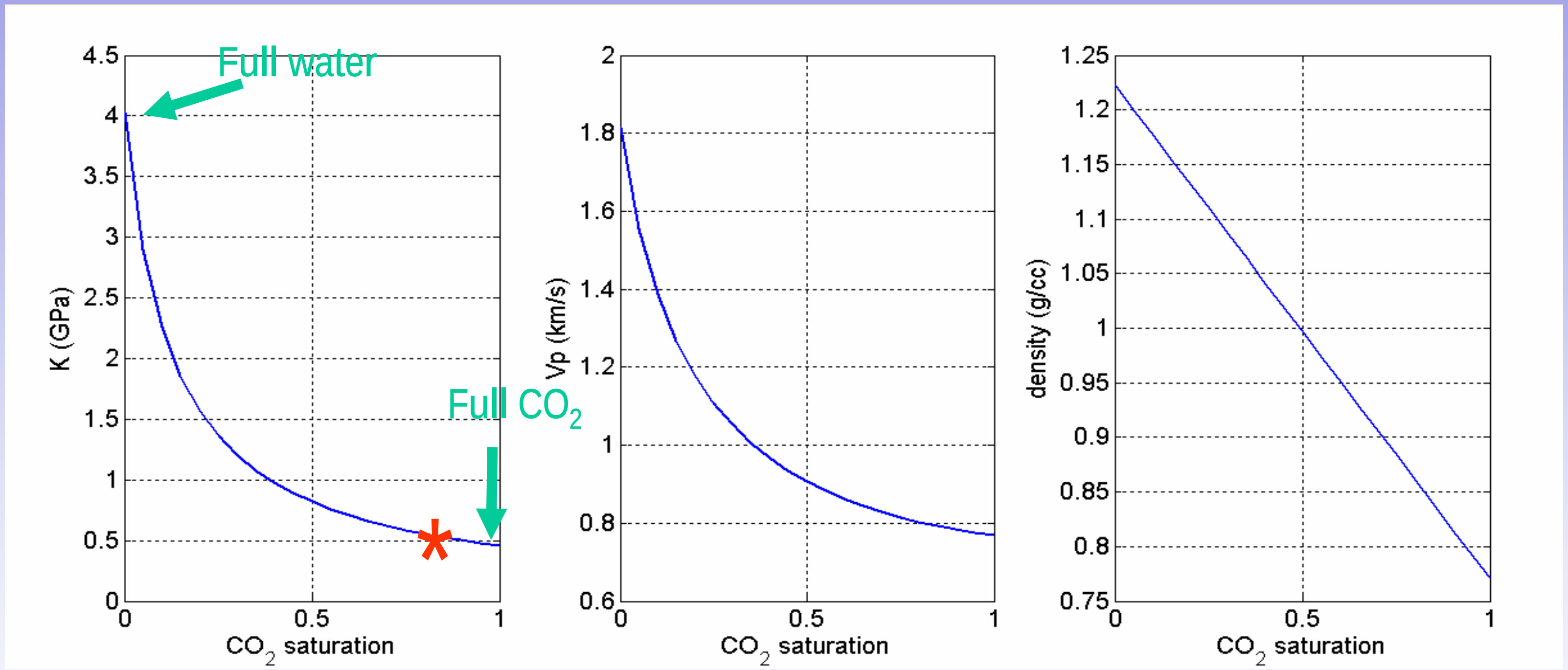


Very good match between the modified equations and the lab data

Brine properties in-situ (62°C)

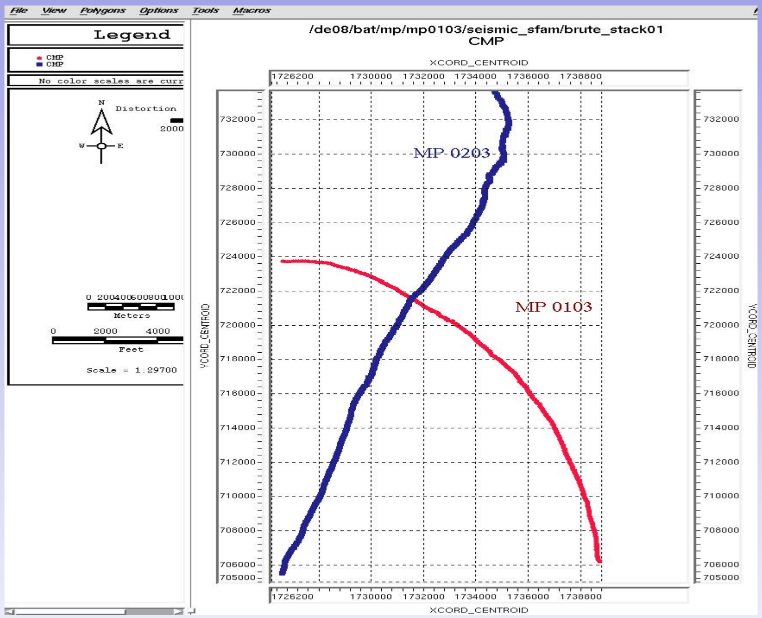


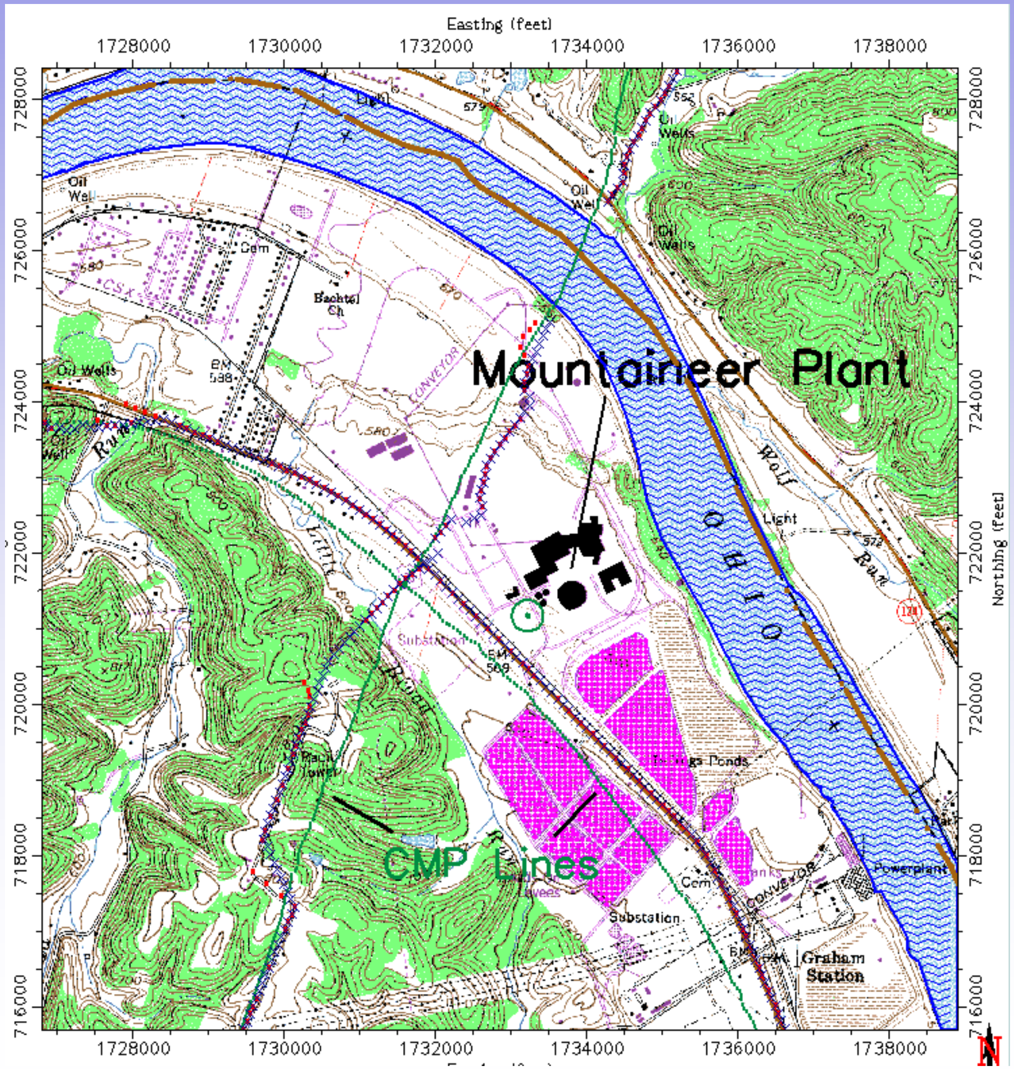
Fluid mixture property: CO_2 + brine in-situ



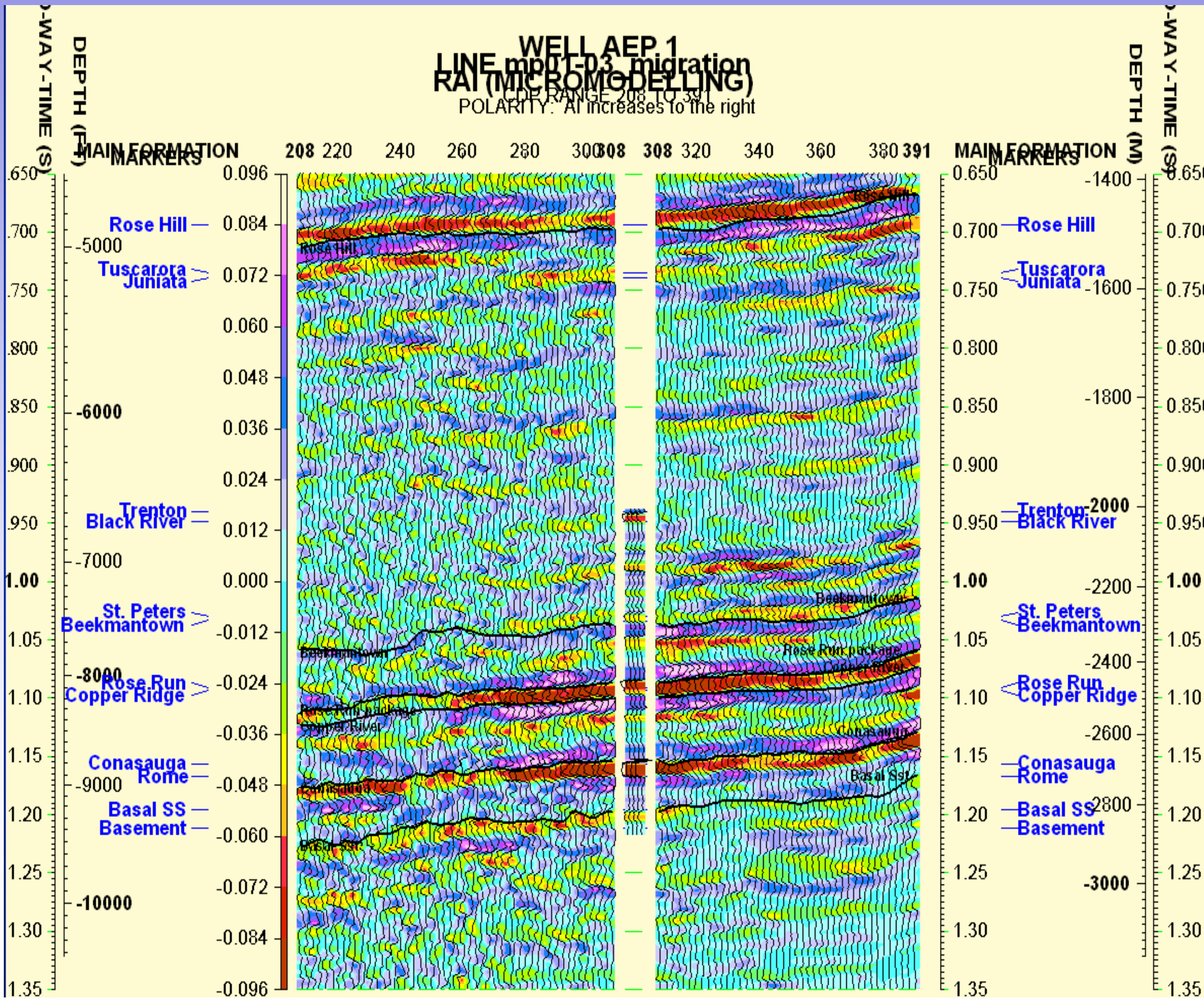
Using modified Batzle-Wang equation + Wood’s relation

Appalachian Basin area feasibility study: Seismic lines near AEP-1 well



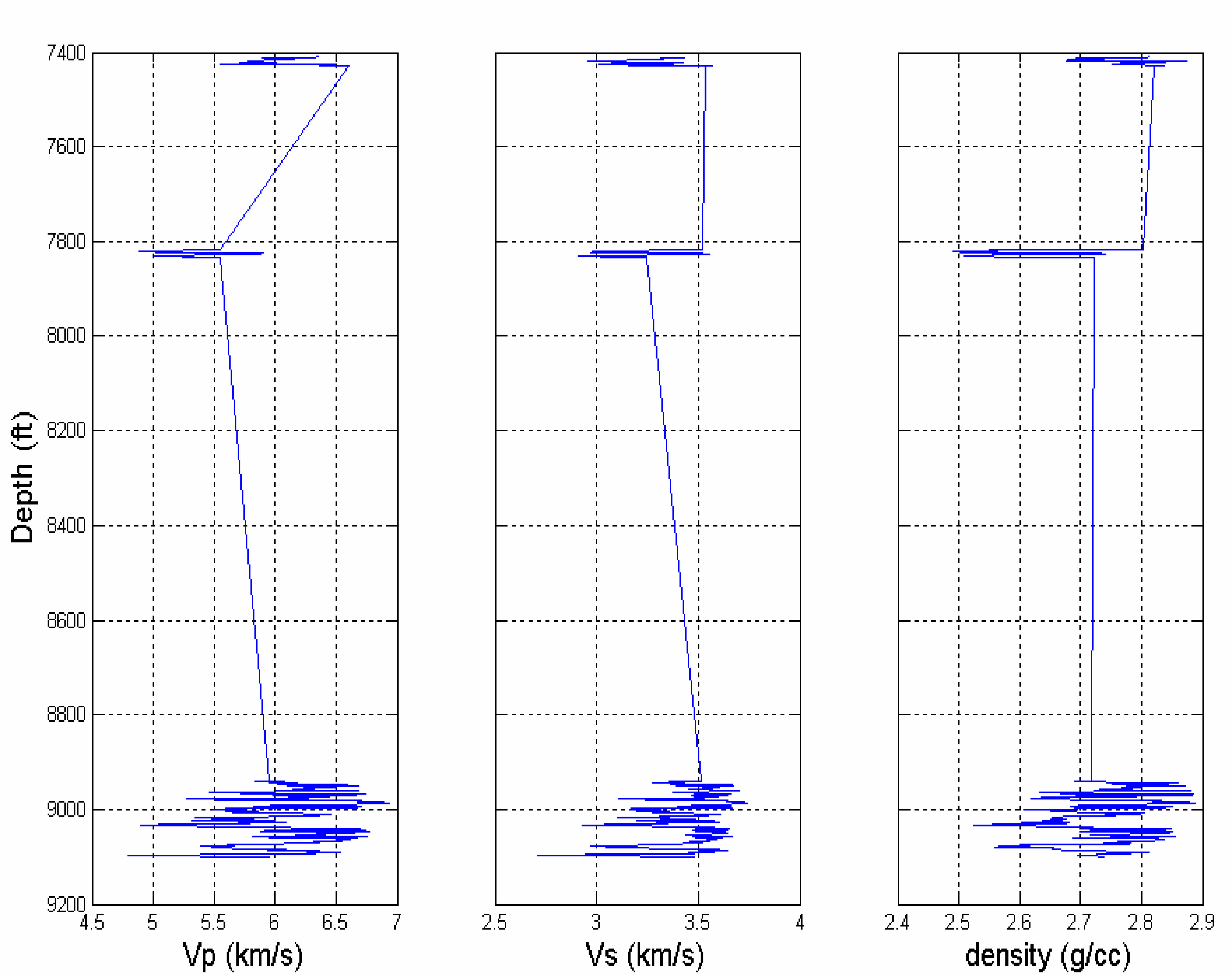


AEP-1 well: three zones of interests



- Lateral continuous
- Thin
- Data quality

Three potential injection zones

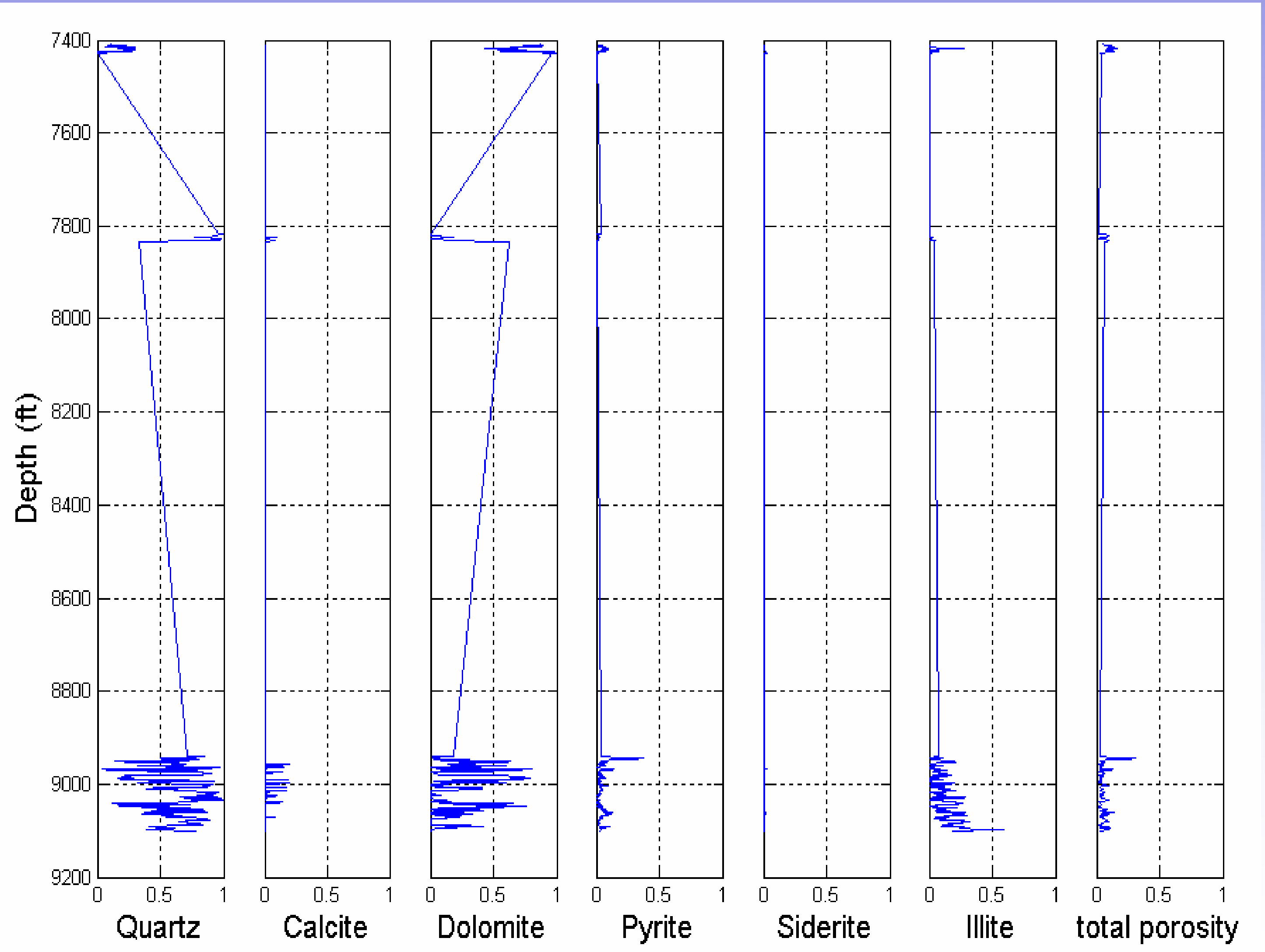


Beekmantown dolomite

Rose Run sandstone

Basal sandstone

Three potential injection zones

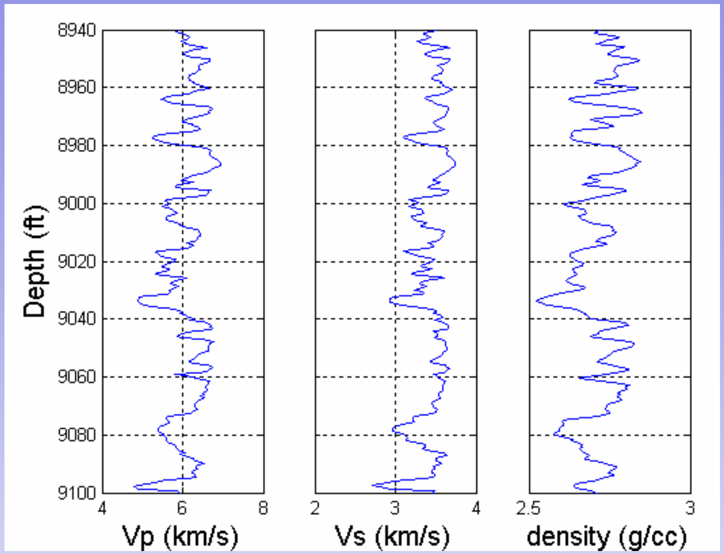


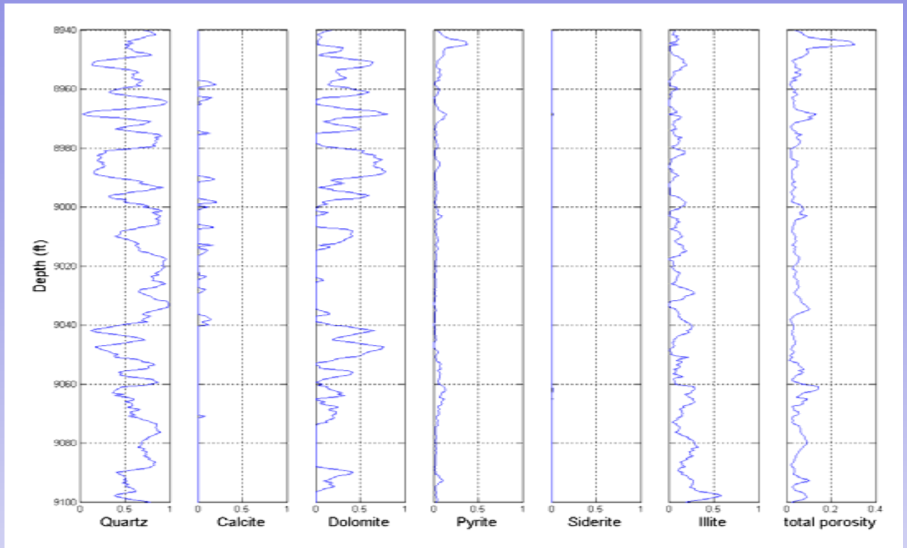
Beekmantown dolomite

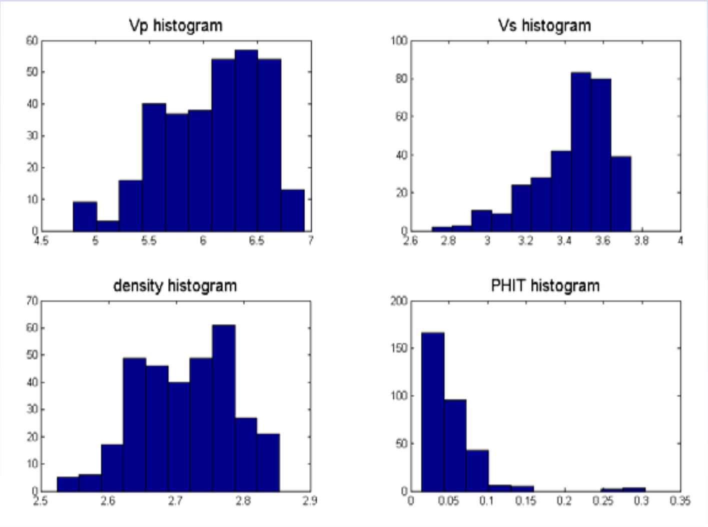
Rose Run sandstone

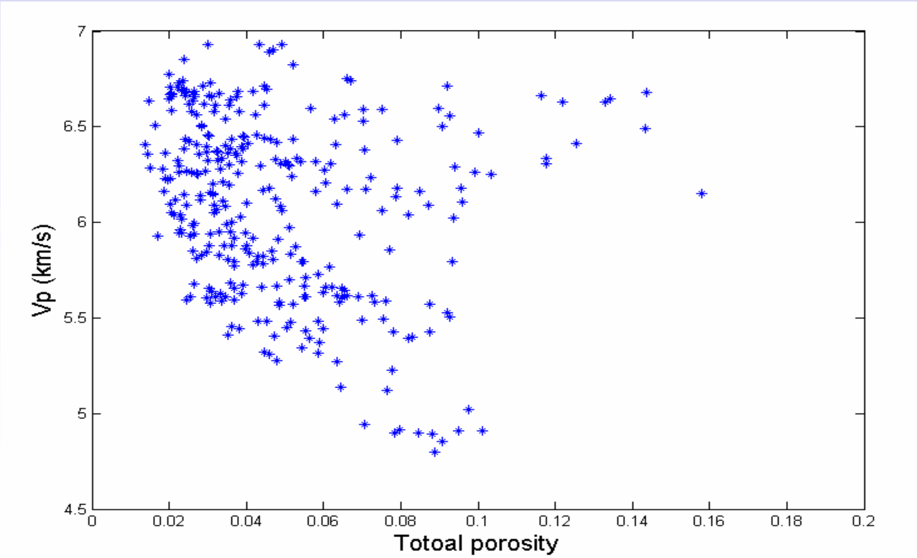
Basal sandstone

Basal Sandstone

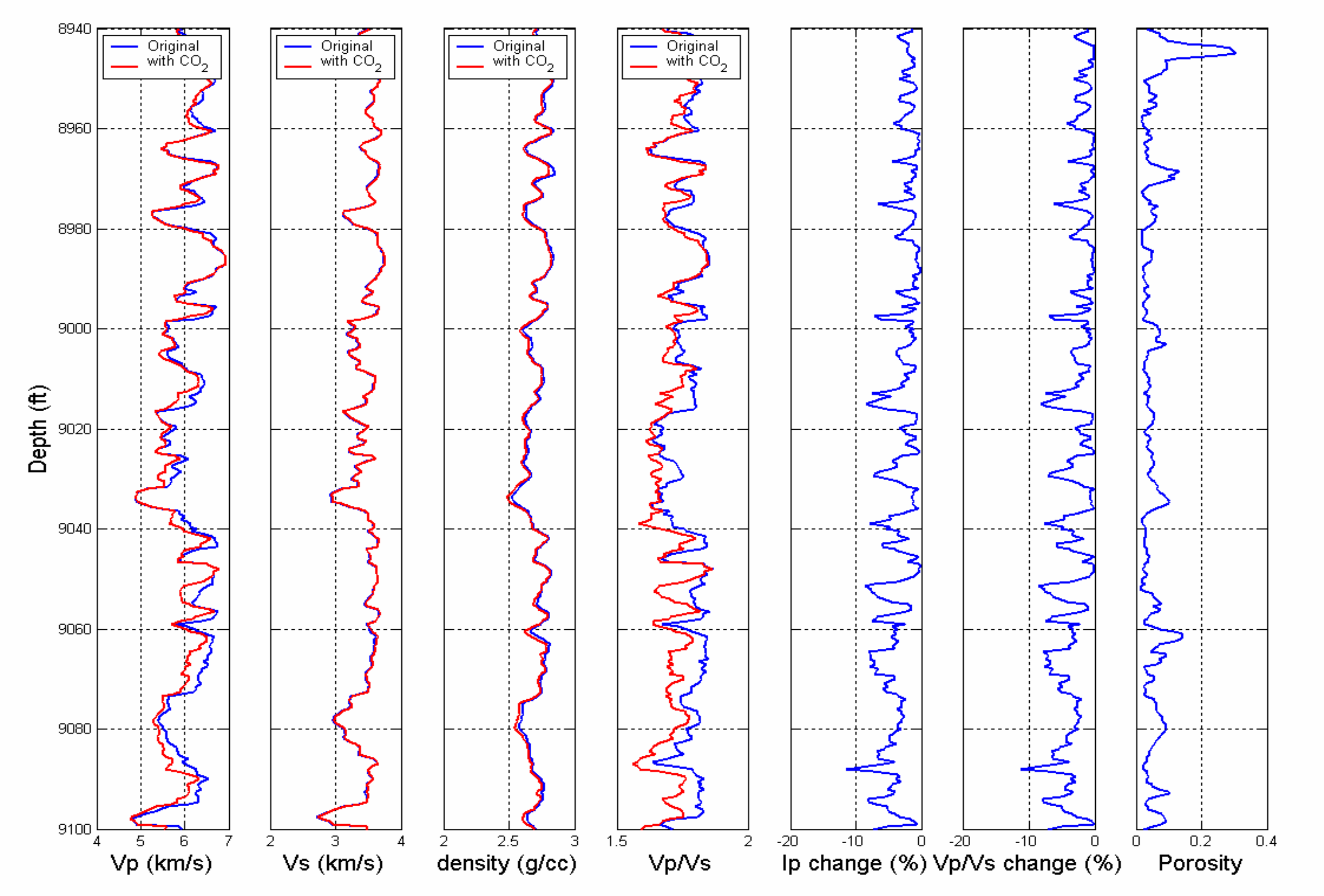








Gassmann fluid substitution



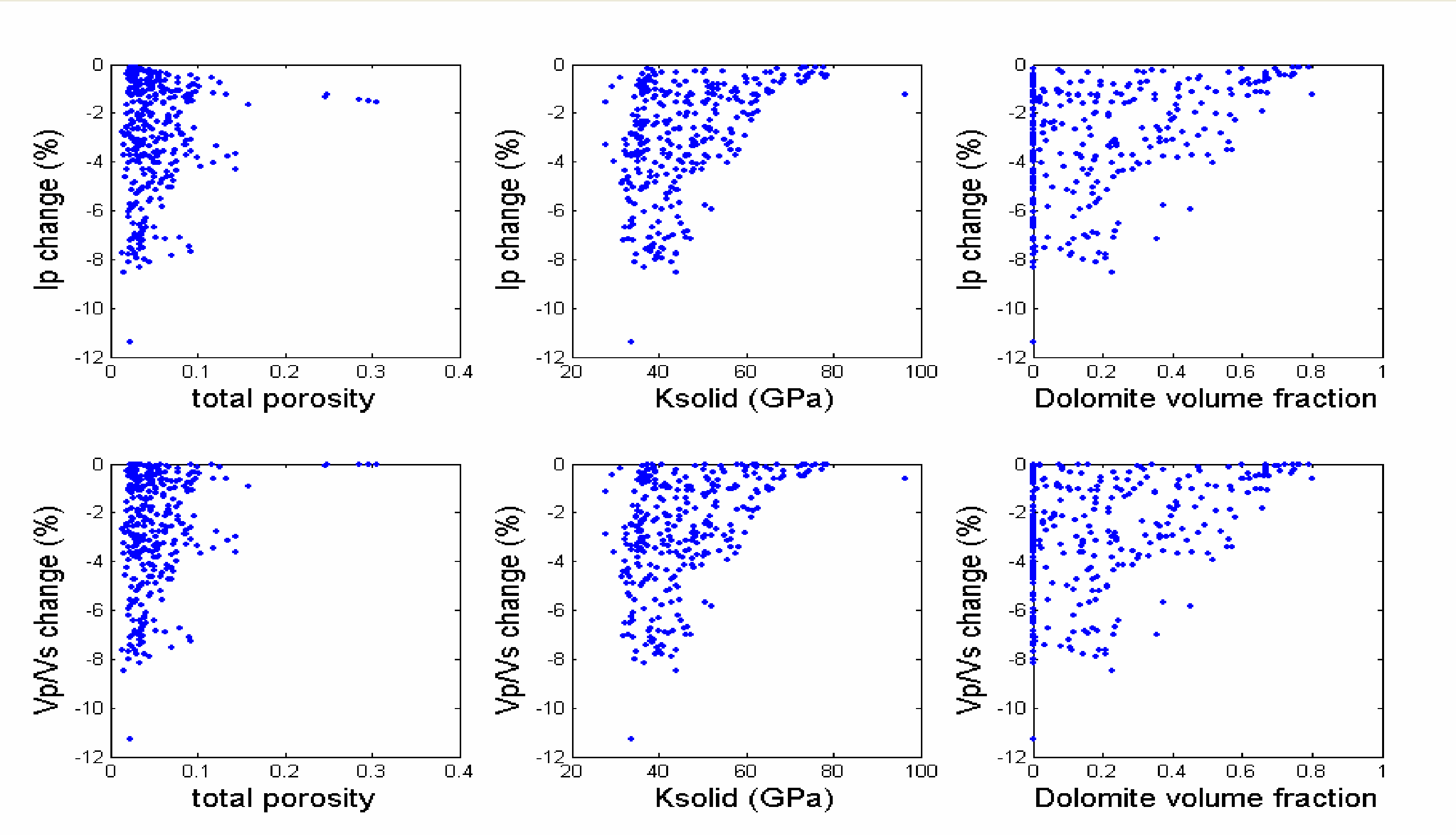
I_p & V_p/V_s changes

Mostly <8%

- CO_2 sweep efficiency → related to permeability

  75~90% may be a possible reachable CO_2 saturation.
- Fluid properties calculated using modified Batzle-Wang + Wood's relation
- Fluid substitution through Gassmann's equation

I_p & V_p/V_s changes

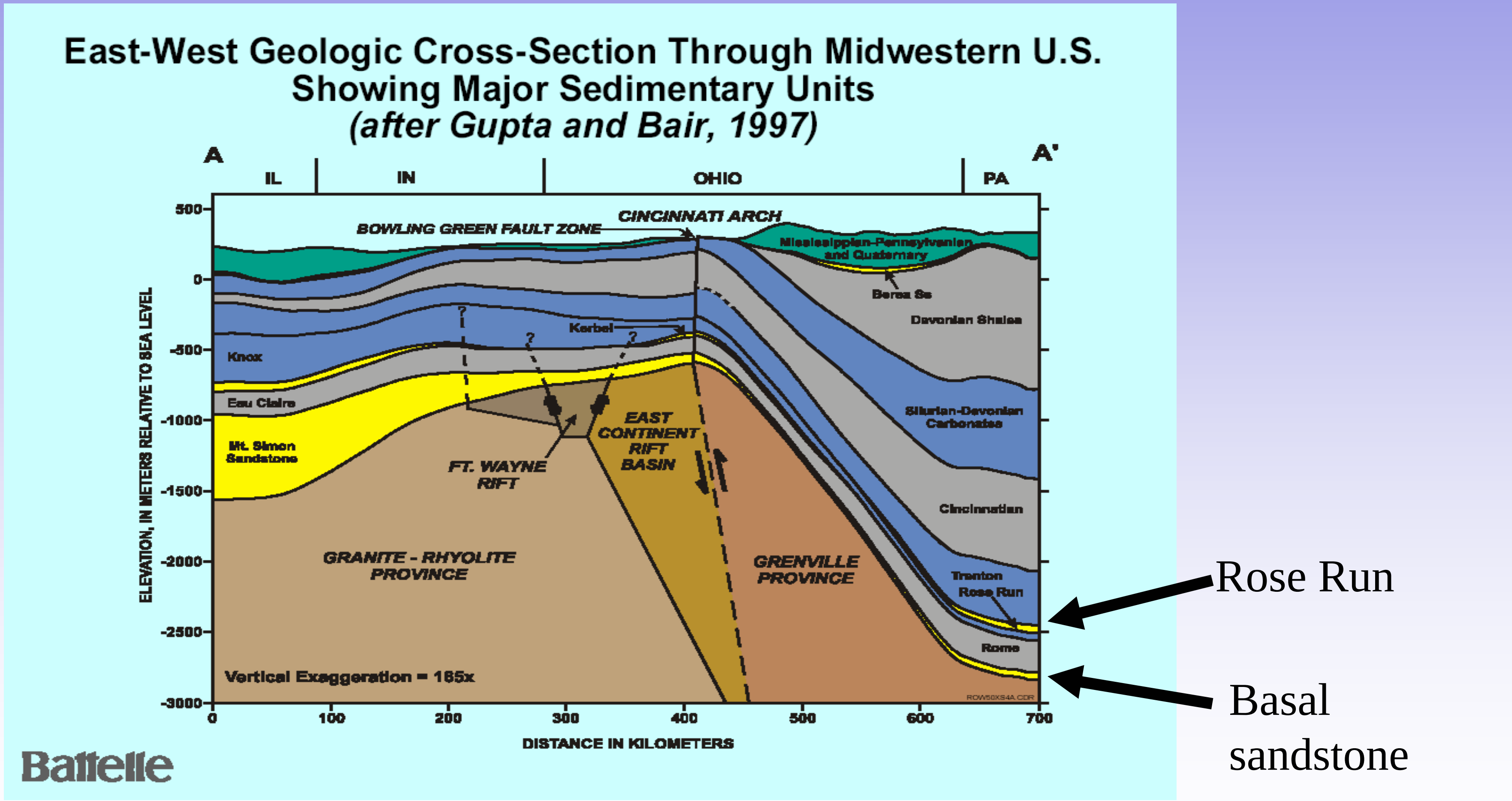


Seismic property changes are more significant in soft rocks

→ small K_{solid}

→ more changes in quartz-rich zones

Structural Cross-Section - Regional



From Ryder et al., 1996, USGS Map Series I-2495

Ohio River Valley Regional analogs

Before	vp km/s	vs km/s	density g/cc	porosity %	pressure psi	temperature oC	Kfl GPa	rofl g/cc	vpfl km/s
W-Ohio	5.18	3.05	2.70	12	1050.	32	2.915	1.083	1.641
C-Indiana	5.33	3.05	2.70	10	2500	50	3.359	1.133	1.722
N-C-Ohio	5.18	3.05	2.70	14	1000	32	2.760	1.060	1.613

After	vp km/s	vs km/s	density g/cc	porosity %	pressure psi	temperature oC	Kfl GPa	rofl g/cc	vpfl km/s
W-Ohio	4.94	3.07	2.65	12	1700	32	0.031	0.698	0.210
C-Indiana	5.05	3.06	2.67	10	3500	50	0.166	0.843	0.444
N-C-Ohio	5.00	3.07	2.66	14	2000	32	0.052	0.760	0.261

Changes	P-impedance change %	Vp/Vs change %
W-Ohio	-6.33	-5.52
C-Indiana	-6.31	-5.80
N-C-Ohio	-5.00	-4.25

Depth Ranges	ft
W-Ohio	2807-3147
C-Indiana	4000-5000
N-C-Ohio	2450-2800

- **Changes on the order of ~5% or 6% at ~3000-4000 ft subsurface can be detected by current seismic**

Conclusions

- Revised B-W equation match lab data of CO_2 better
- 4D sensitivity
  - More 4D signature in quartz-rich zones
  - Further increase of saturation does not produce a large 4D change
  - Challenges in hard-rock environment necessitates further research
- Regional differences
  - Typical 4D response is ~2-8%
  - Easier to pick up 4D response from shallower formations
- Future efforts
  - Continued evaluation of novel approaches to design seismic monitoring surveys for deep basin settings
  - Verification of seismic monitoring feasibility in Ohio Valley Region as part of regional partnership work