Feasibility of Geophysical Monitoring of Carbon-Sequestrated Deep Saline Aquifers

Project Number DE-FE0001160

Subhashis Mallick, Vladimir Alvarado,
Amit Padhi, Xiao Wang, Hamid Behzadi

University of Wyoming

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage

August 21-23, 2012

Outline

- Benefits to the program
- Project Overview
- Technical Status
- Accomplishments to date
- Summary

Benefit to the Program

- **The research project is aimed at:**
  - Developing methods to monitor the CO_2 plume movements within the sequestrated reservoir volumes.
  - Account for the totality of the injected CO_2.
- **It serves one of the major goals of the program:**
  - Develop technologies to demonstrate that 99 percent of injected CO_2 remains within the injection zones.

Project Overview:
Goals and Objectives

- **Project Objectives:**
  - Combine multiphase reservoir simulation with seismic modeling and inversion.
  - Verify if seismic data could be effectively used in predicting CO_2 saturation within the sequestrated reservoir volumes.
- **Project Goal:**
  - Develop technologies to demonstrate that 99 percent of injected CO_2 remains within the injection zones.

Technical Status

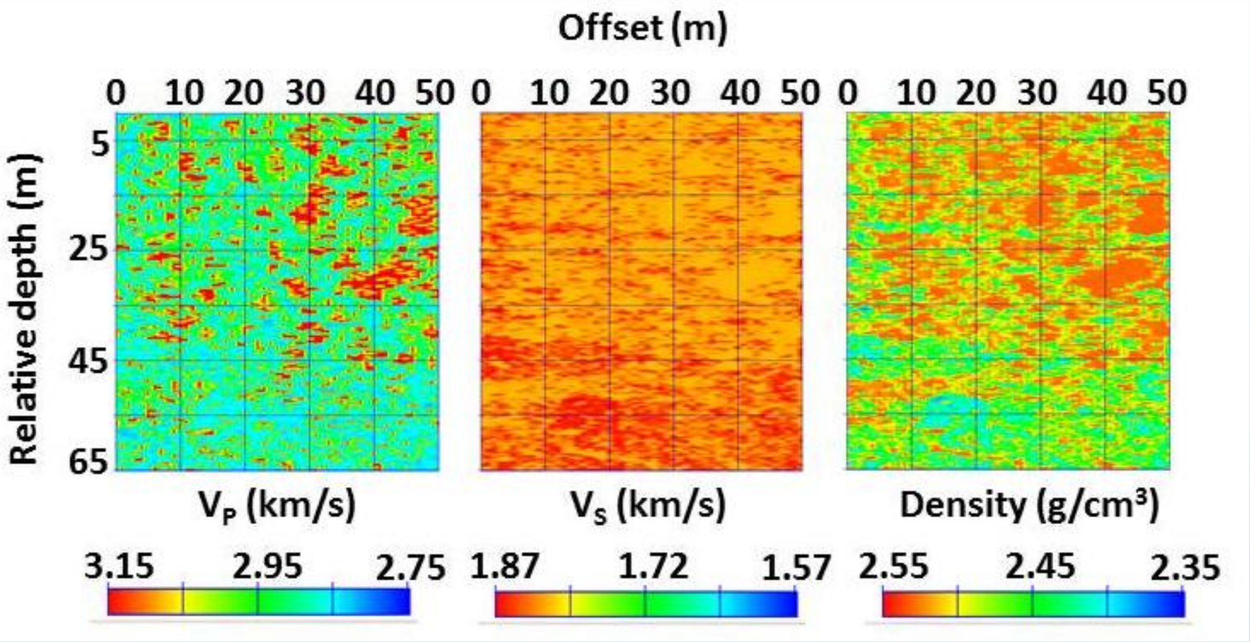
Seismic Waveform Inversion

CO_2 Saturation Prediction

Flow simulation | **Seismic simulation**

UNIVERSITY OF WYOMING

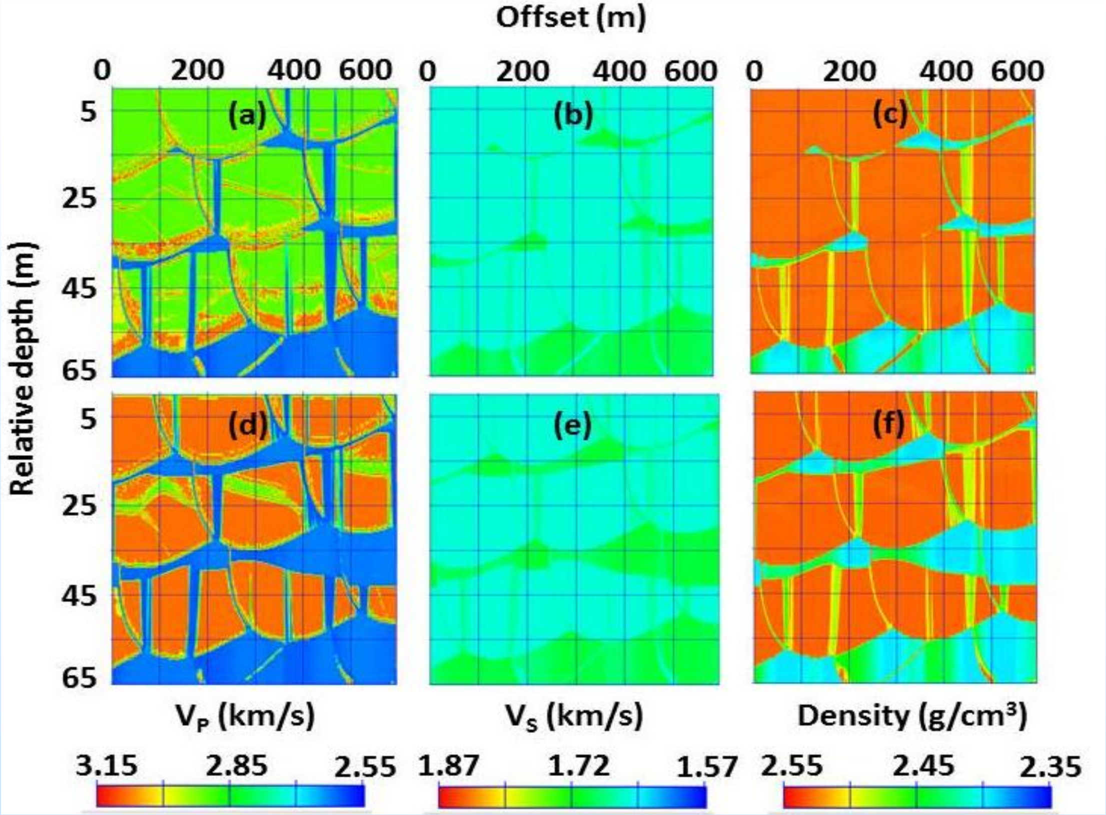
Technical Status- Flow Simulation



Randomly uncorrelated model:

- CO_2 sequestrated at the bottom of the reservoir
- The model shown is 25 years after sequestration

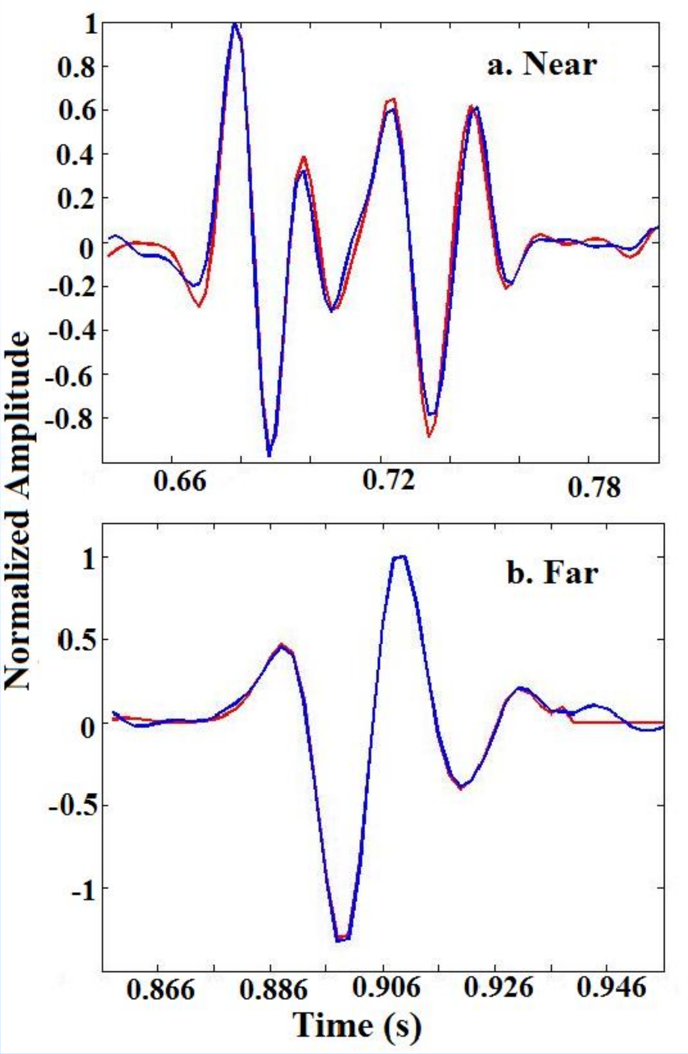
Technical Status- Flow Simulation



Eolian sand depositional system:

- CO_2 sequestrated from the bottom of the reservoir
- (a)-(c) the model 5 years after sequestration
- (d)-(f) the model 55 years after sequestration.

Technical Status- Seismic Simulation

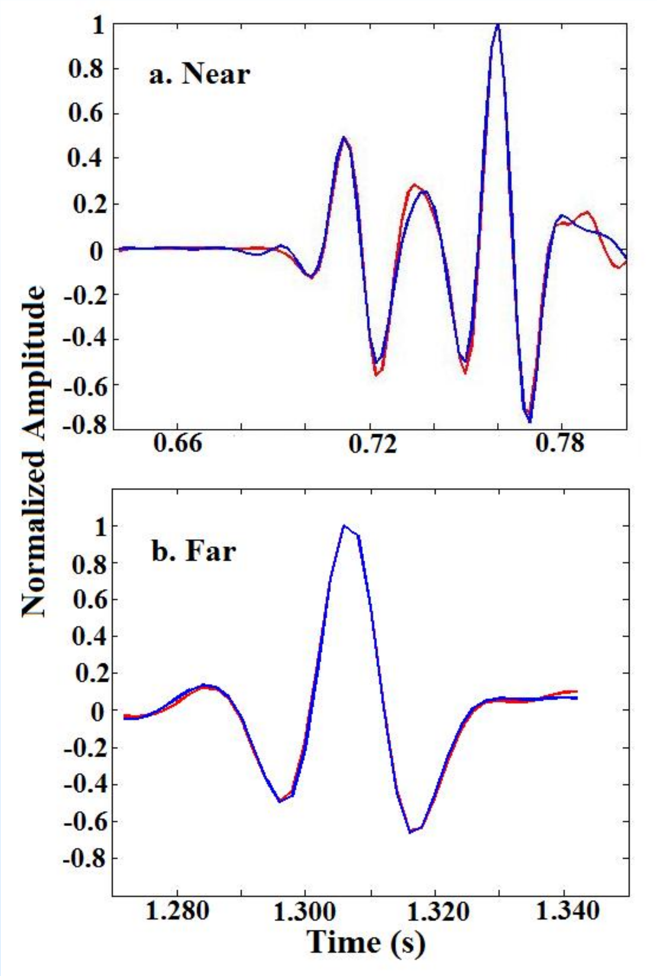


Seismic Modeling of the random system:

- The red curve is the finite-difference computed seismic response from the reservoir using the exact reservoir model.
- The blue curve is the computed response where the exact reservoir model is replaced by an equivalent model of a few homogeneous layers.
- For the random system, the equivalent layers were all isotropic.

UNIVERSITY OF WYOMING

Technical Status- Seismic Simulation



Seismic Modeling of the eolian system:

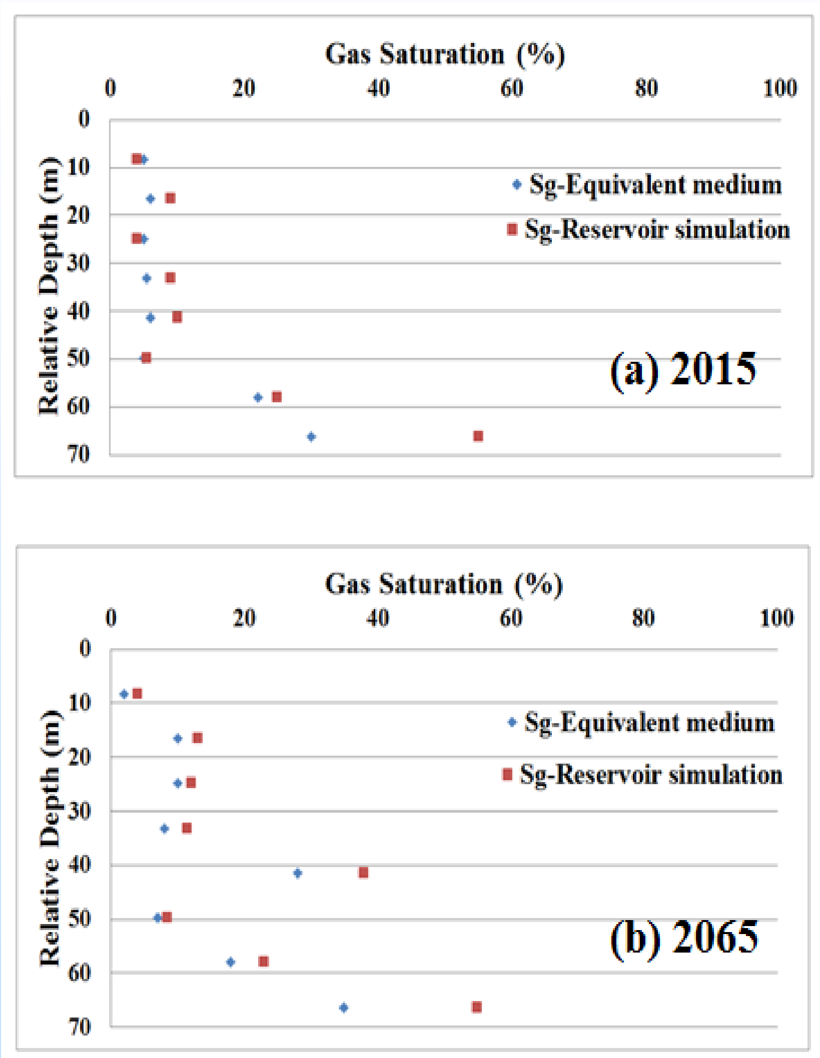
- The red and blue curves are the same as they were for the random
- The equivalent layers needed to be anisotropic.

Take-away message:

- CO_2 sequestration into realistic reservoir systems induce apparent anisotropy in the observed time-lapse seismic responses.
- For an accurate strategy for MVA, the seismic anisotropy cannot be ignored.

University of Wyoming

Technical Status- Saturation Prediction

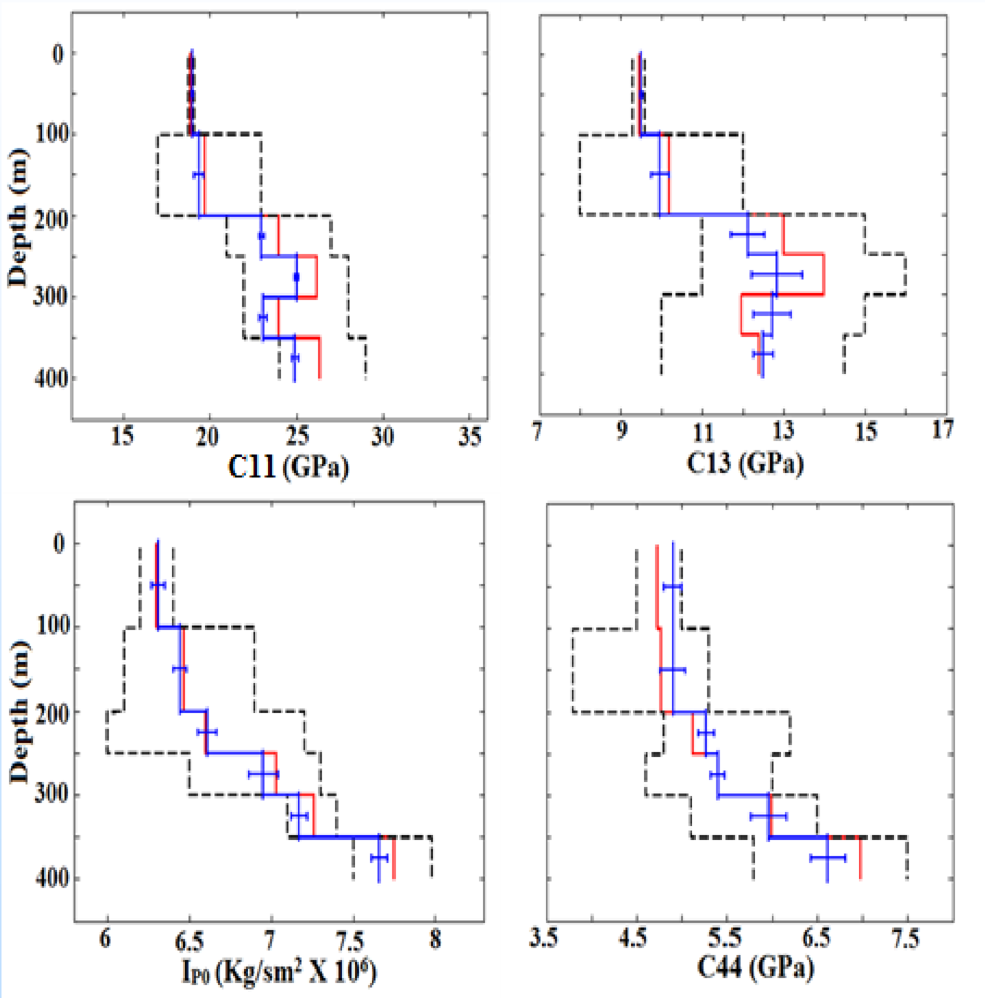


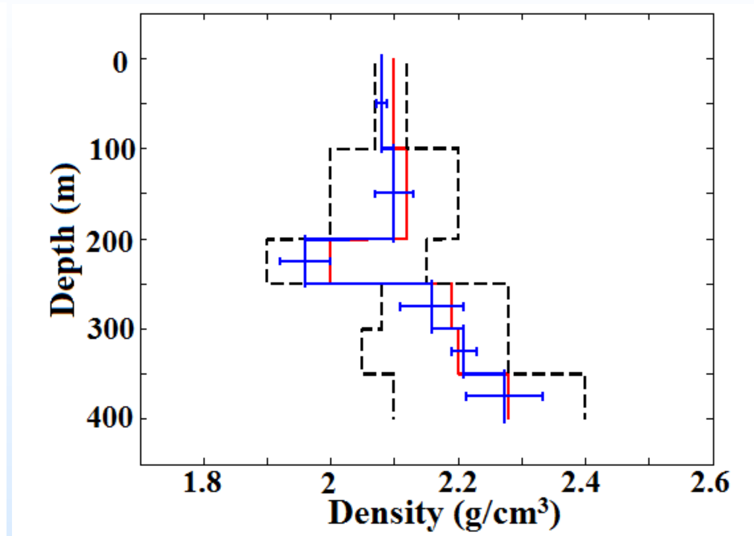
Equivalent anisotropic models could reasonably predict CO_2 saturation.

Take-away messages:

- If time lapse seismic data could be inverted for anisotropic elastic properties →
  - Equivalent anisotropic properties can potentially predict the CO_2 saturation
- Important elements to a successful MVA →
  - Anisotropic seismic inversion
  - Calibration of seismic inversion with flow simulation

Technical Status- Seismic Waveform Inversion





Red Curves → True model
Blue Curves → Inverted model
Black (dashed) curves → Search window

UNIVERSITY OF WYOMING

Technical Status- Anisotropic Inversion

Take-away messages:

- Time-lapse seismic data could be inverted for anisotropic properties of the sequestrated reservoir volumes.
- These extracted anisotropic properties could then be used to predict CO_2 saturation within the reservoirs.
- Multicomponent seismic data are required for an accurate extraction of elastic parameters and density from data.

University of Wyoming

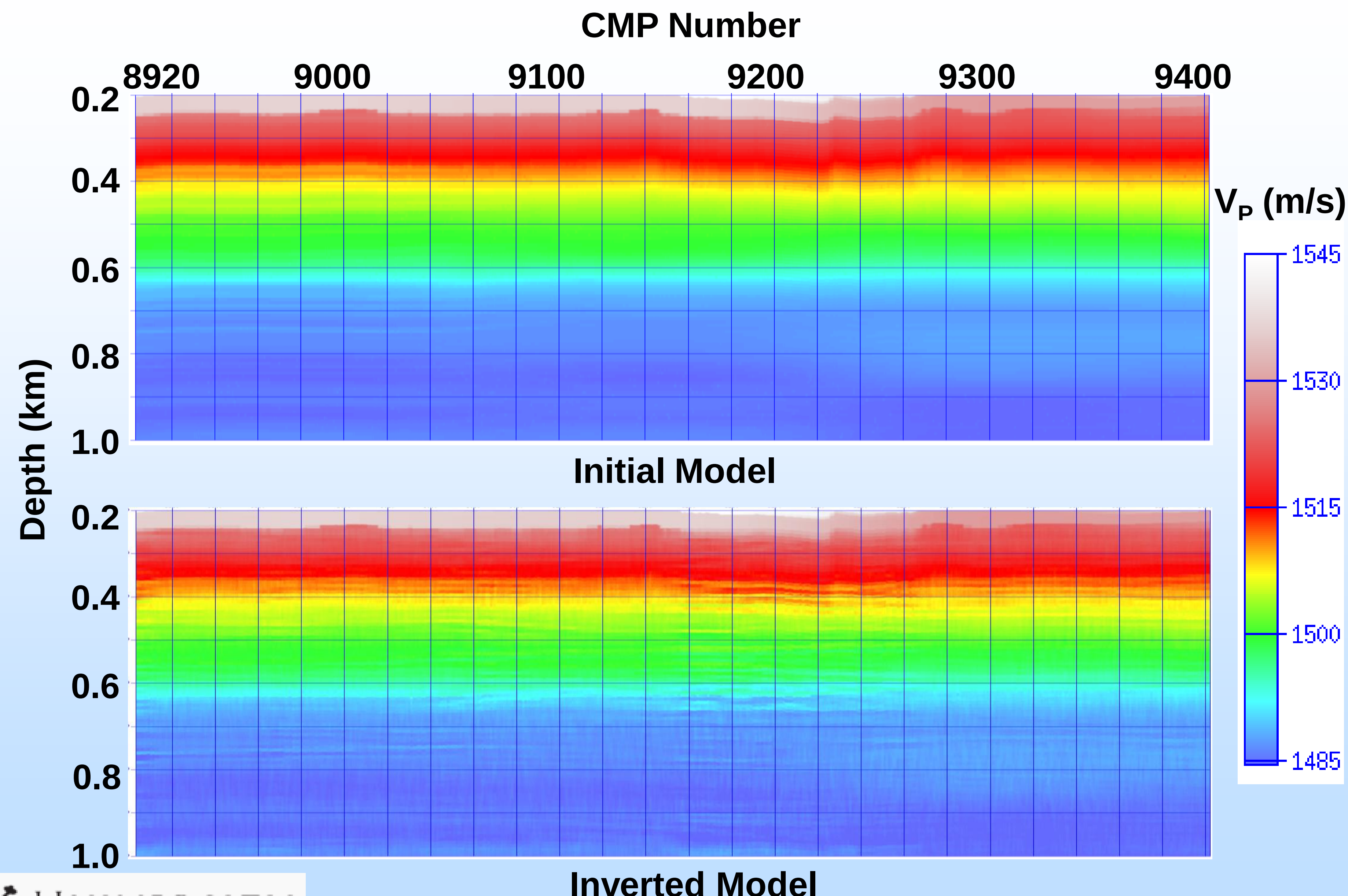
Accomplishments to Date

- **Prestack waveform inversion (PWI) methodology:**
  - Isotropic PWI is complete.
  - A prototype anisotropic PWI is developed and is being tested.
- **Demonstration of a complete workflow:**
  - Calibrating seismic simulations with reservoir flow modeling.
  - Predicting the saturation of the injected CO_2 during the post-sequestration phases.

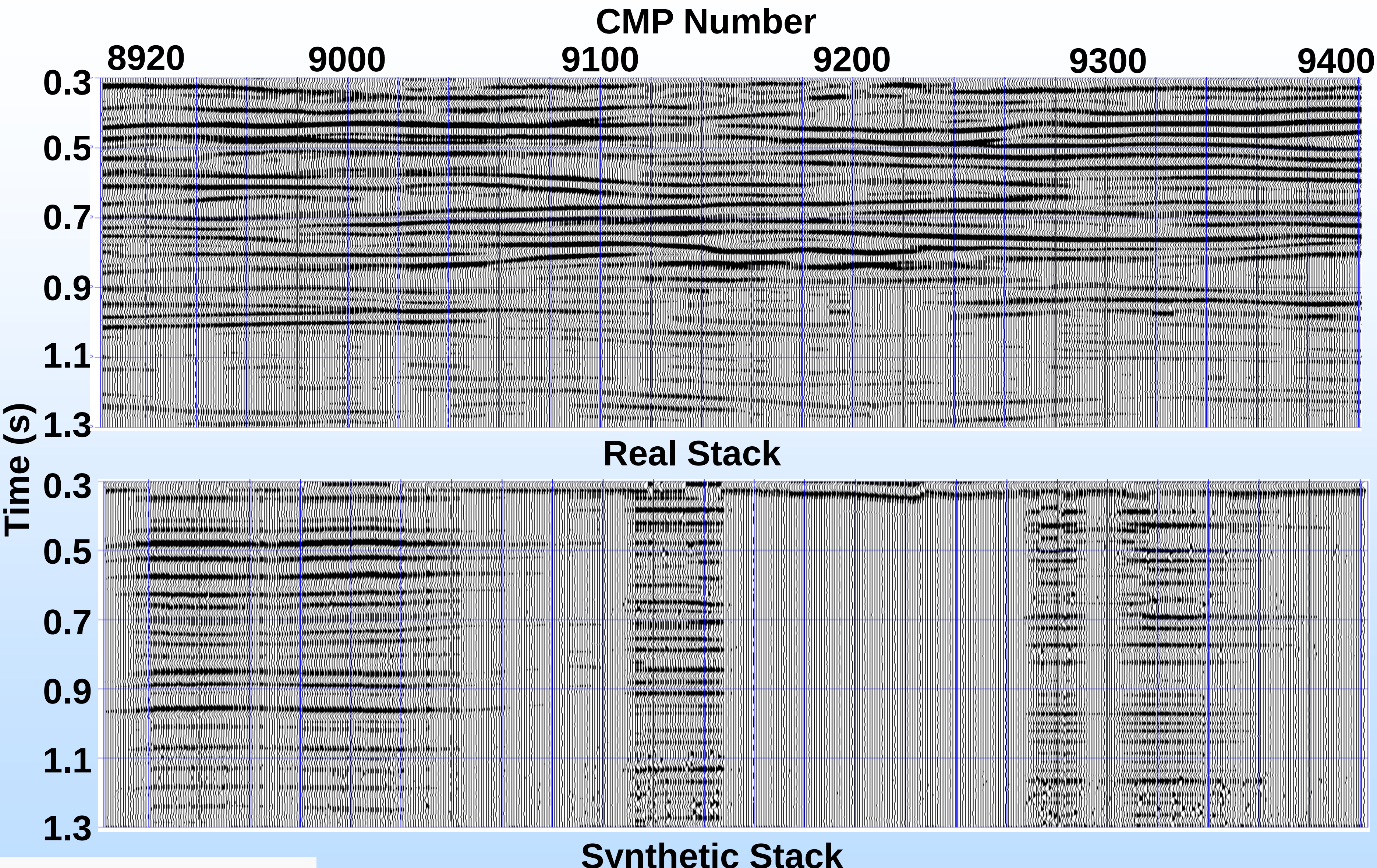
Summary

- **Key Findings**
  - Saturation of the injected CO_2 could be predicted by a proper calibration of seismic simulations with reservoir flow modeling.
- **Lessons Learned**
  - CO_2 injection induces anisotropy in observed seismic responses
  - A correct MVA strategy should include:
    - Acquisition and inversion of multicomponent seismic data
    - Flow modeling and calibration of seismic data with simulation models.
    - Anisotropic inversion for prediction of CO_2 saturation

PWI Example – Real data from South China Sea

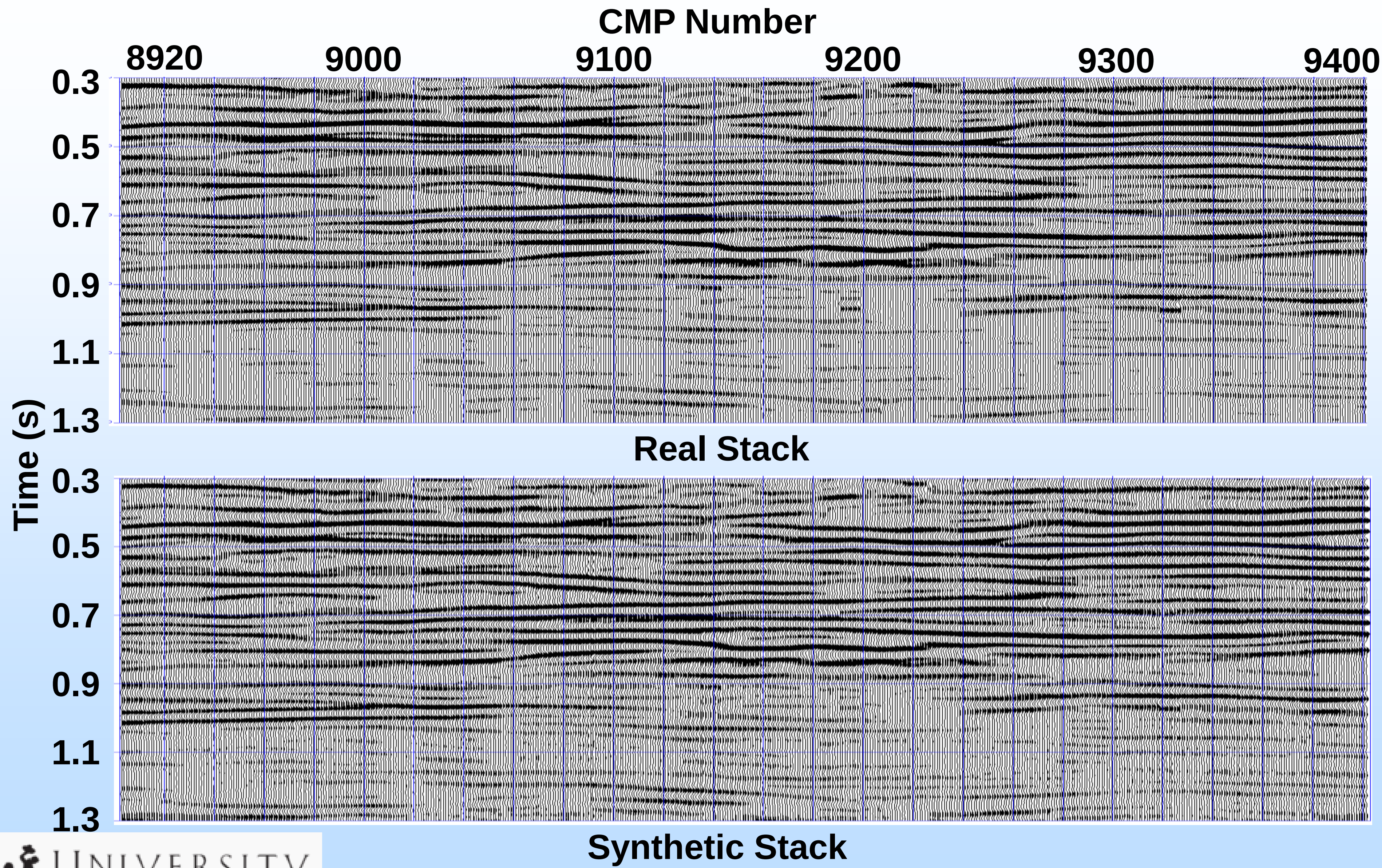


Data Prediction (before inversion)

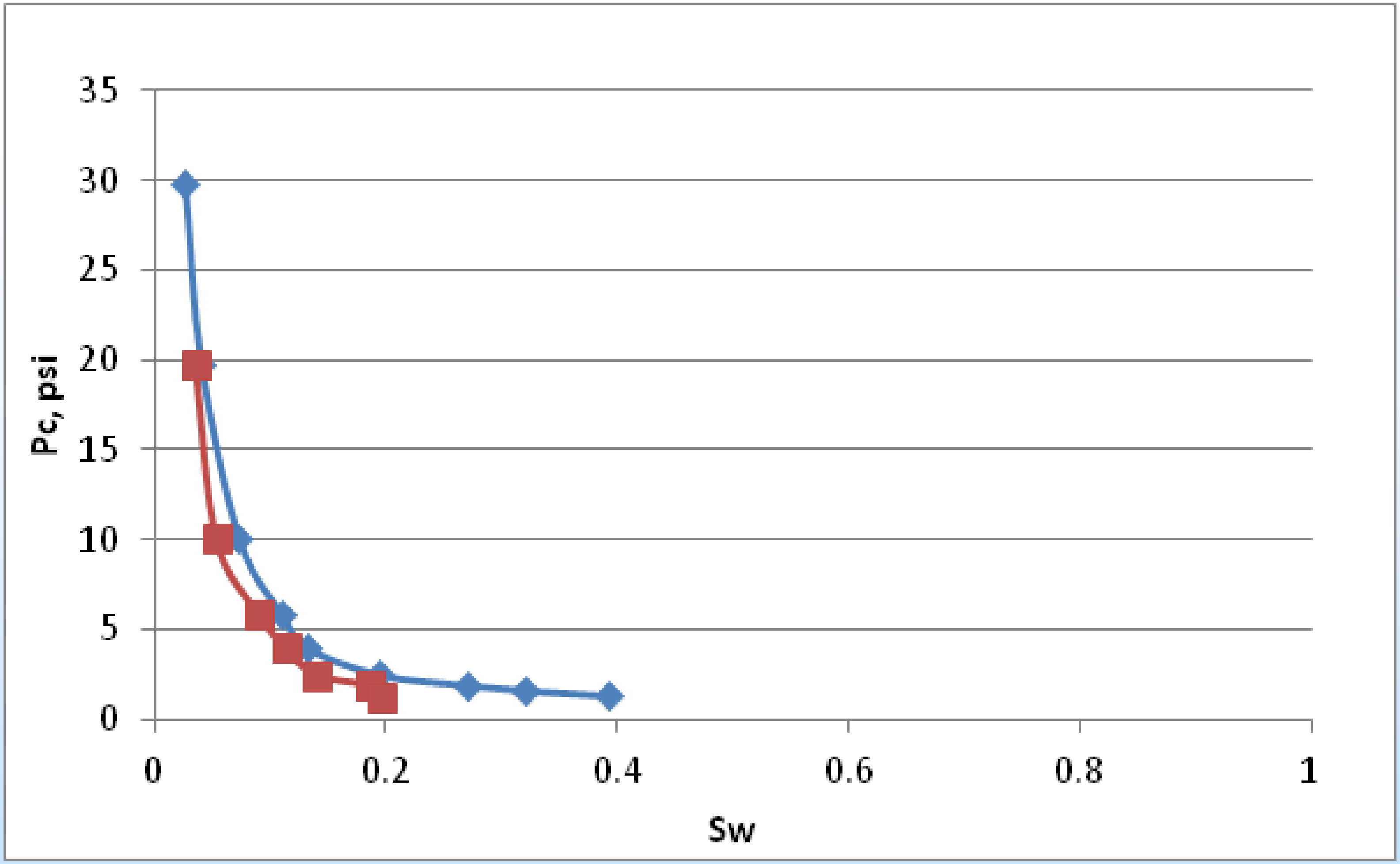


University of Wyoming

Data Prediction (after inversion)



UNIVERSITY OF WYOMING



Drainage and imbibition curves →Minnelusa formation, an analog of the Tensleep formation of the Rock-Spring uplift

UNIVERSITY OF WYOMING

Summary

- **Future Plans**
  - Saturation experiments with Rock-Springs core samples.
  - Flow modeling on Rock-Springs reservoir models.
  - Seismic simulations on Rock-Springs reservoir models and calibrate observed responses with the CO_2 saturation within the reservoir.
  - Complete the development of an anisotropic PWI.
  - Demonstrate application of anisotropic PWI on (synthetic) time-lapse seismic data in predicting the CO_2 saturation during the post-injection phases.

Acknowledgements

- **DOE/NETL**
- **Schlumberger/WesternGeco**

Thank You