3D Prestack Waveform Inversion - A Real Data Example from the Rock Springs Uplift, Wyoming*

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Abstract

Development and application of computationally efficient seismic inversion methods for accurate estimation of subsurface properties is a big challenge in seismic exploration. The current state-of-the-art amplitude-variation-with-offset inversions do not account for complex wave propagation effects, which are important for accurate inversion. Some methods like prestack waveform inversion (PWI) solve the full wave equation and have given high quality results. PWI is very computation-intensive and was thus rewritten in a multilevel parallelization scheme successfully applied to 2D seismic data. Since 3D seismic data provide more stratigraphic details than 2D data, this study extends the work to 3D data collected at the Rock Springs Uplift in Wyoming, US for the purpose of CO_2 sequestration. Our PWI uses a genetic algorithm and a forward model named reflectivity method to iteratively compute synthetic data and compare them to observed data until the best match is obtained.

It takes about 20 min of CPU time to invert one common midpoint (CMP) location. For our 3D volume of 30,976 CMPs, it would take about 10,325 hours (~1.2 years), which is not practical. PWI was thus redesigned in a two-level parallelization scheme using the concept of pseudo-master nodes and pseudo-slaves. This assigns N nodes to invert the data at each CMP and M sets each with N nodes so that the inversion is run simultaneously at M different locations. If we have 352 compute nodes and 2 nodes per computation, we can divide the compute nodes into 176 sets each with 2 nodes (M=176, N=2) and run the inversion simultaneously at each set. With each set inverting 176 CMPs, our 3D volume will be inverted in about 59 hours (~2.4 days) instead of 1.2 years. Applying the method to RSU data helped us accurately capture the primary sealing lithologies (Lower Triassic Dinwoody and Permian Amsden formations) that could prevent an upward migration of CO_2 from the main potential storage formations (Weber Sandstone and Madison Limestone). We also identified secondary potential seals (Baxter Shale) and storage reservoirs (Nugget Sandstone) that could increase the CO_2 storage capacity at the RSU. This multilevel parallelization of PWI shows a drastic cut in computation time and high quality subsurface properties. It is applicable not only to CO_2 storage, but also to hydrocarbon exploration, especially in areas with simple geology. Ongoing research investigates how to handle complex structures using PWI.

3D PRESTACK WAVEFORM INVERSION
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A REAL DATA EXAMPLE FROM THE ROCK SPRINGS UPLIFT, WYOMING

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University of Wyoming

Outline

- **Motivations**
- **Rock Springs Uplift data**
- **3D prestack waveform inversion**
- **Results and discussions**
- **Conclusions**

Motivations

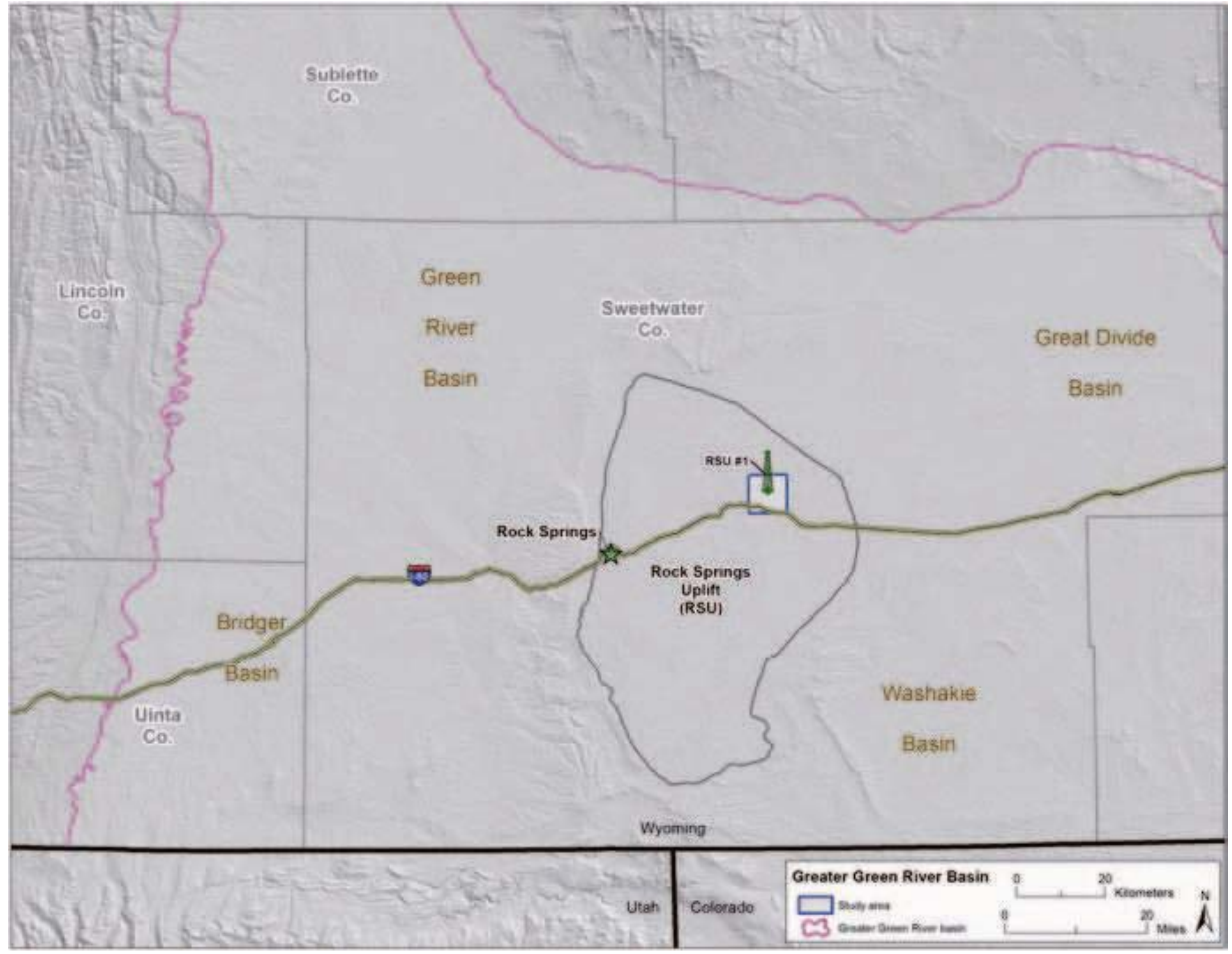
- Accurate estimation of subsurface properties.
  - Challenging task for hydrocarbon exploration.
  - Lithology identification for CO_2 sequestration.

- Invert large data volumes in a more efficient time.
  - Multilevel parallelization of prestack waveform inversion (PWI).

Rock Springs Uplift (RSU) data

- N-S asymmetric anticline.
- 25 mi^2 study area.
- Multicomponent 3D/3C seismic data.
- RSU-1 well log.

- Tensleep/Weber Sandstone.
- Madison Limestone.



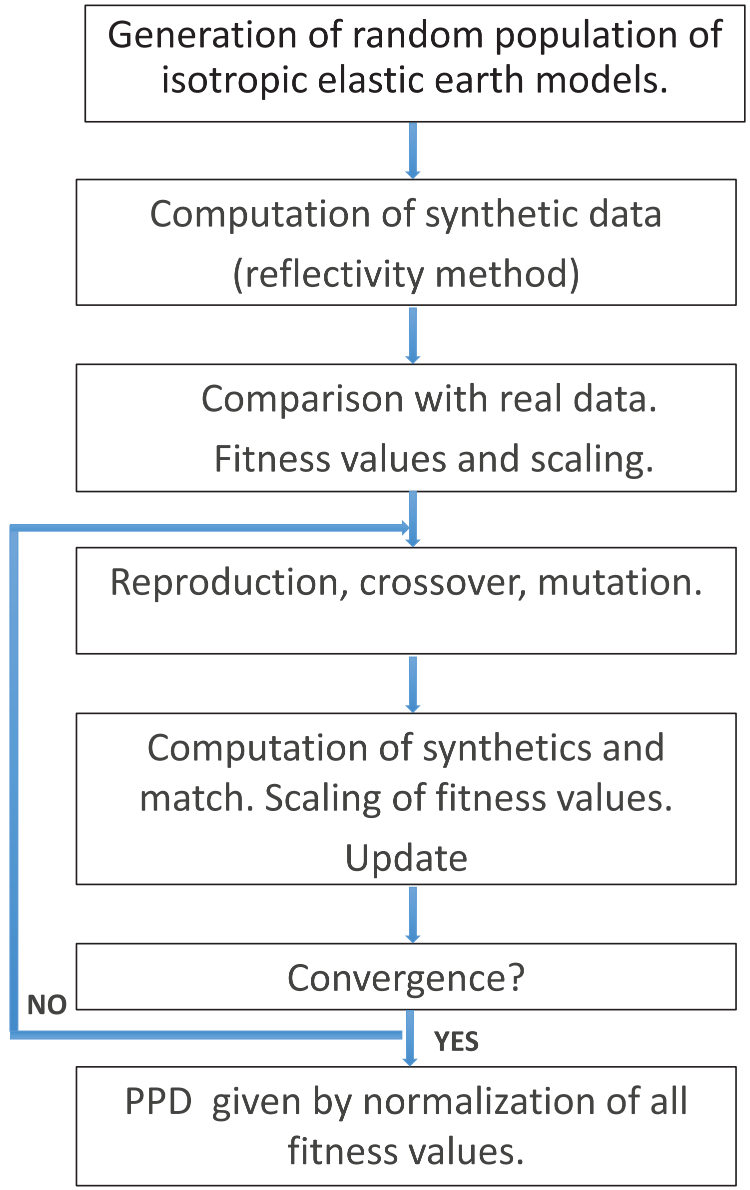
Map of Southwest Wyoming and study area (Courtesy of the Carbon Management Institute, University of Wyoming).

3D prestack waveform inversion

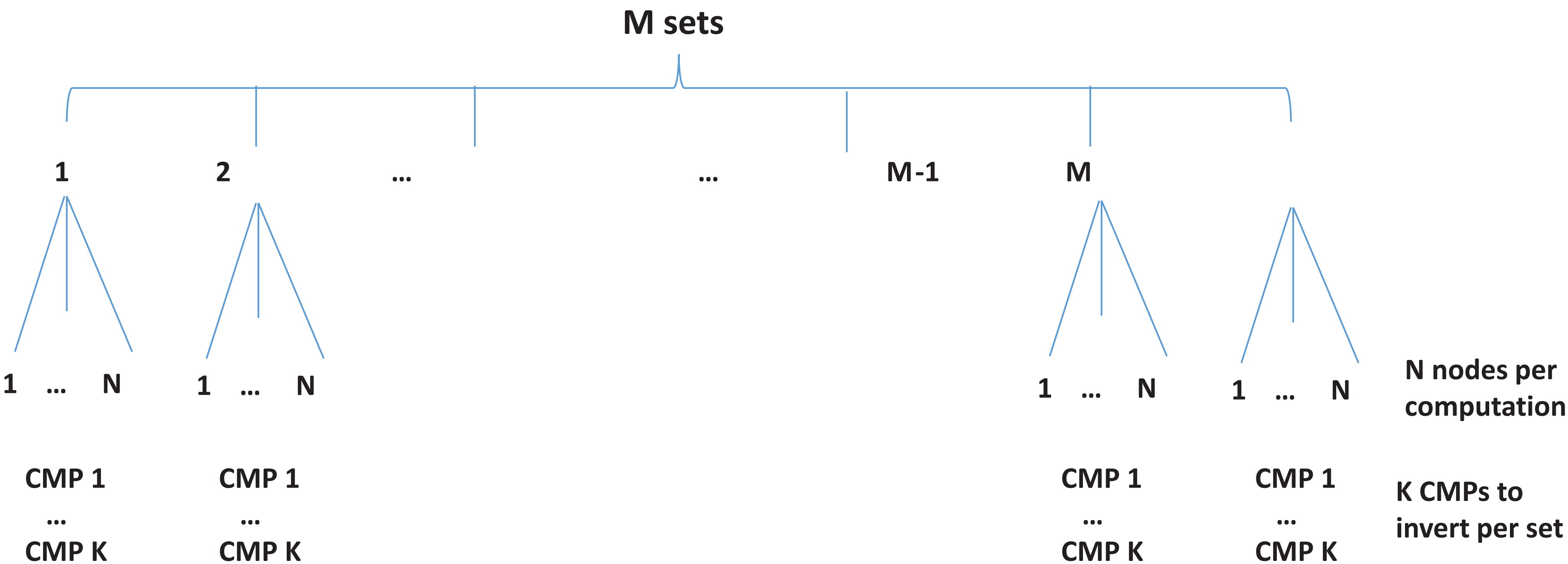
- ❑ Prestack waveform inversion (PWI)
  - ❑ Genetic algorithm (GA) as optimization tool.
  - ❑ Reflectivity Method as forward modeling engine.

- ❑ Multilevel parallelization of PWI

Genetic Algorithm (GA) flow chart



Multilevel parallelization

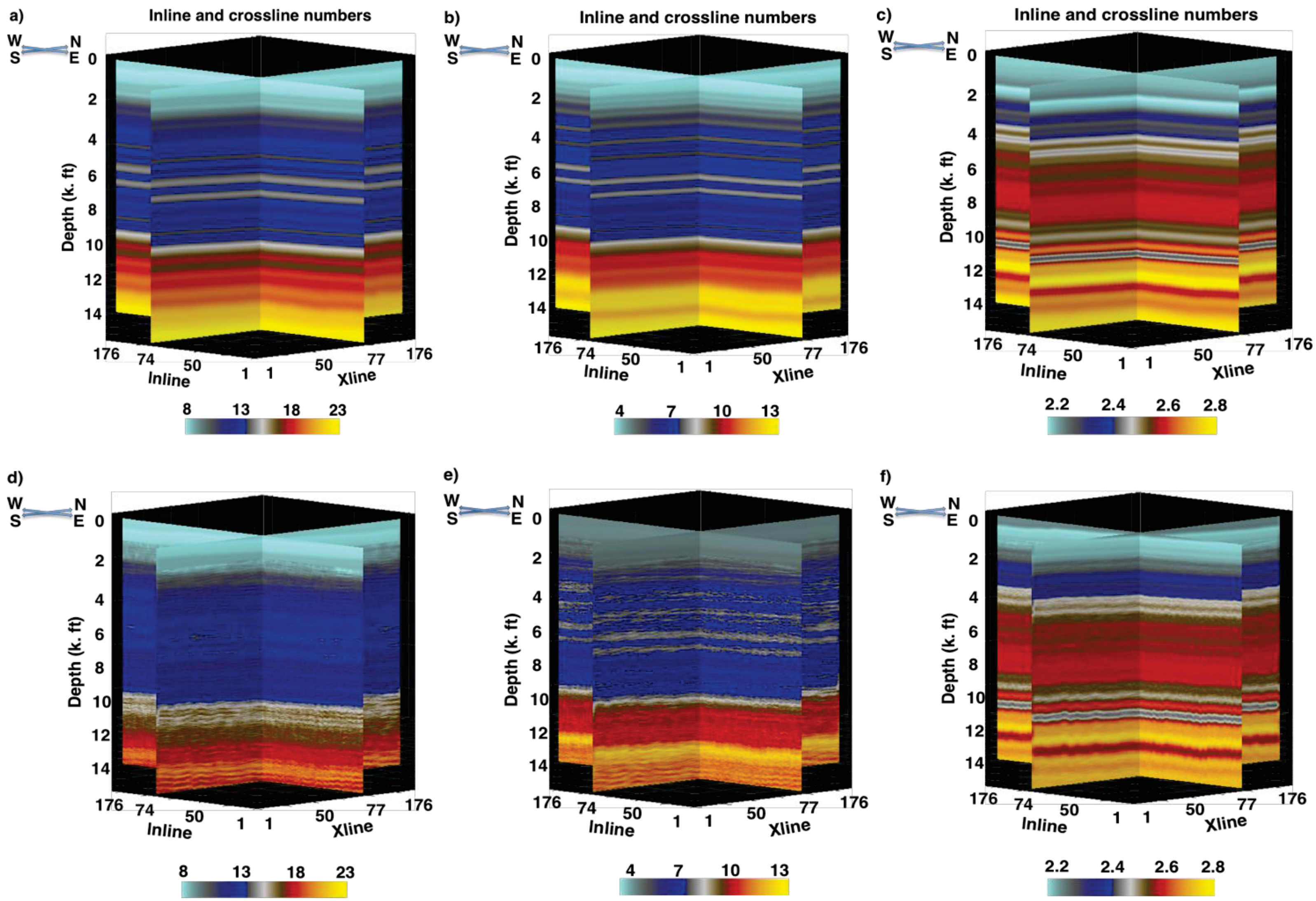


704 compute-nodes
N= 4; M= 176

176*176= 30,976 CMPs
Each set will invert 176 CMPs

Initial models

Inverted models



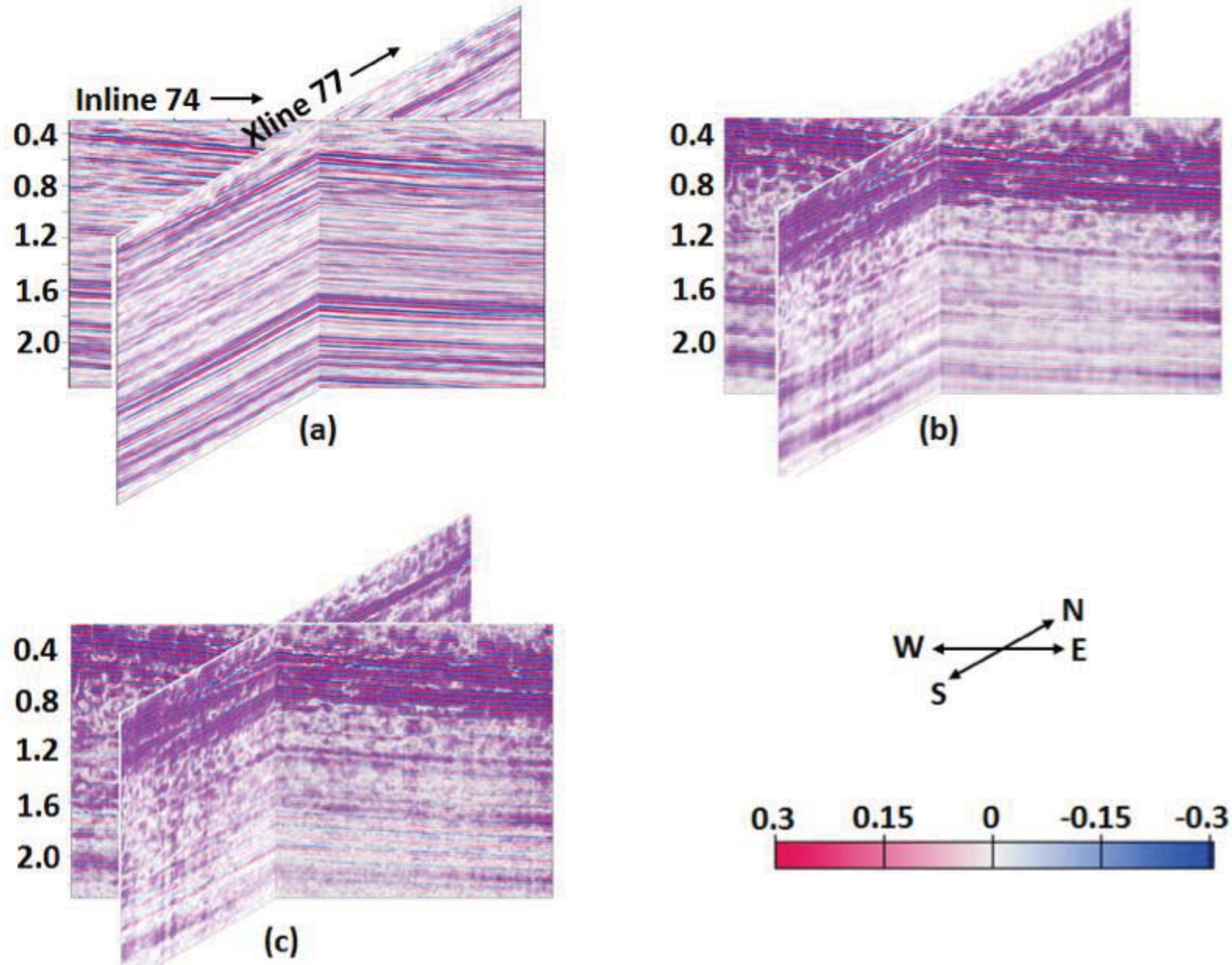
P-wave velocity in k.feet/s

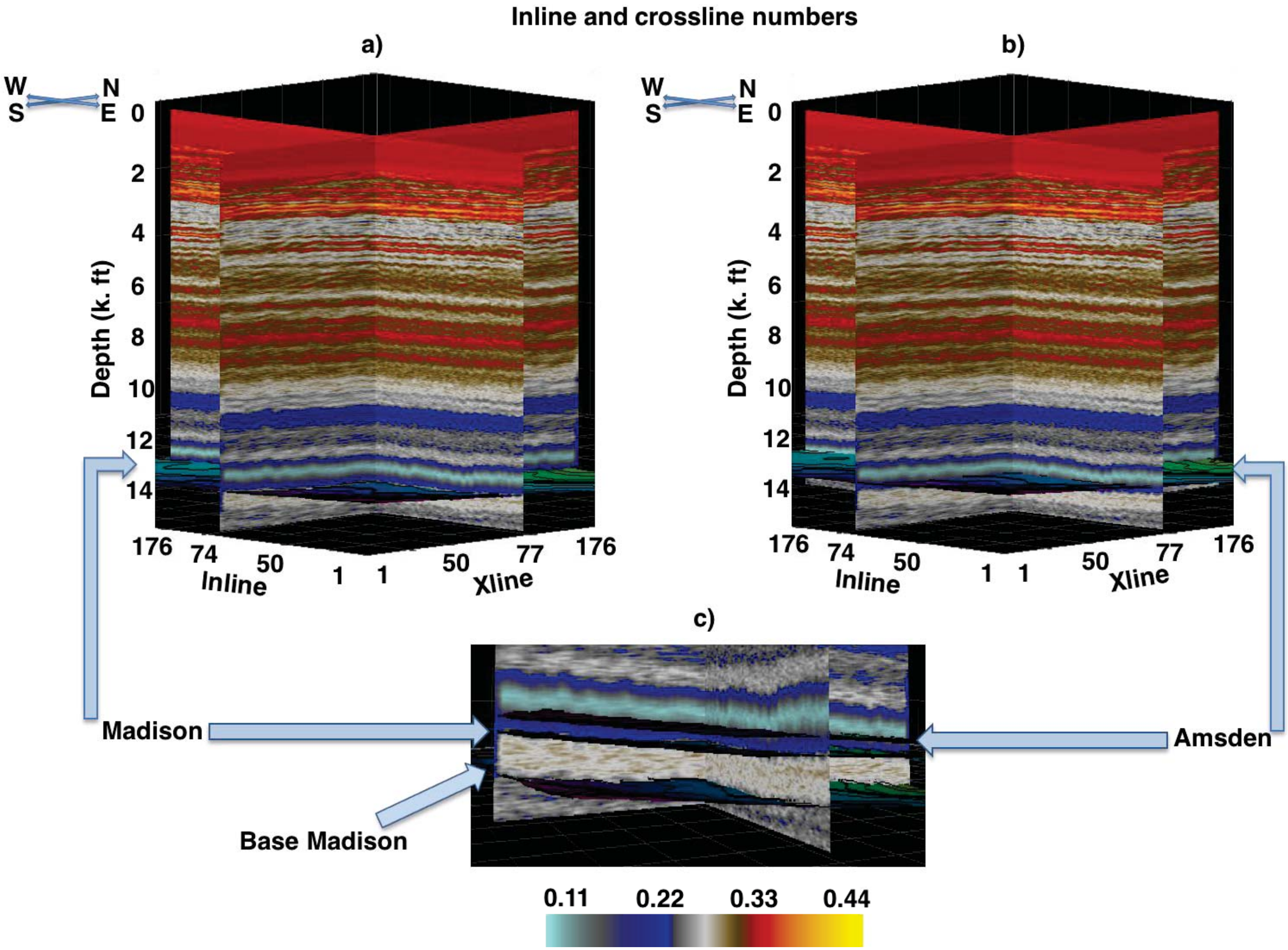
S-wave velocity in k.feet/s

Density in g/cc

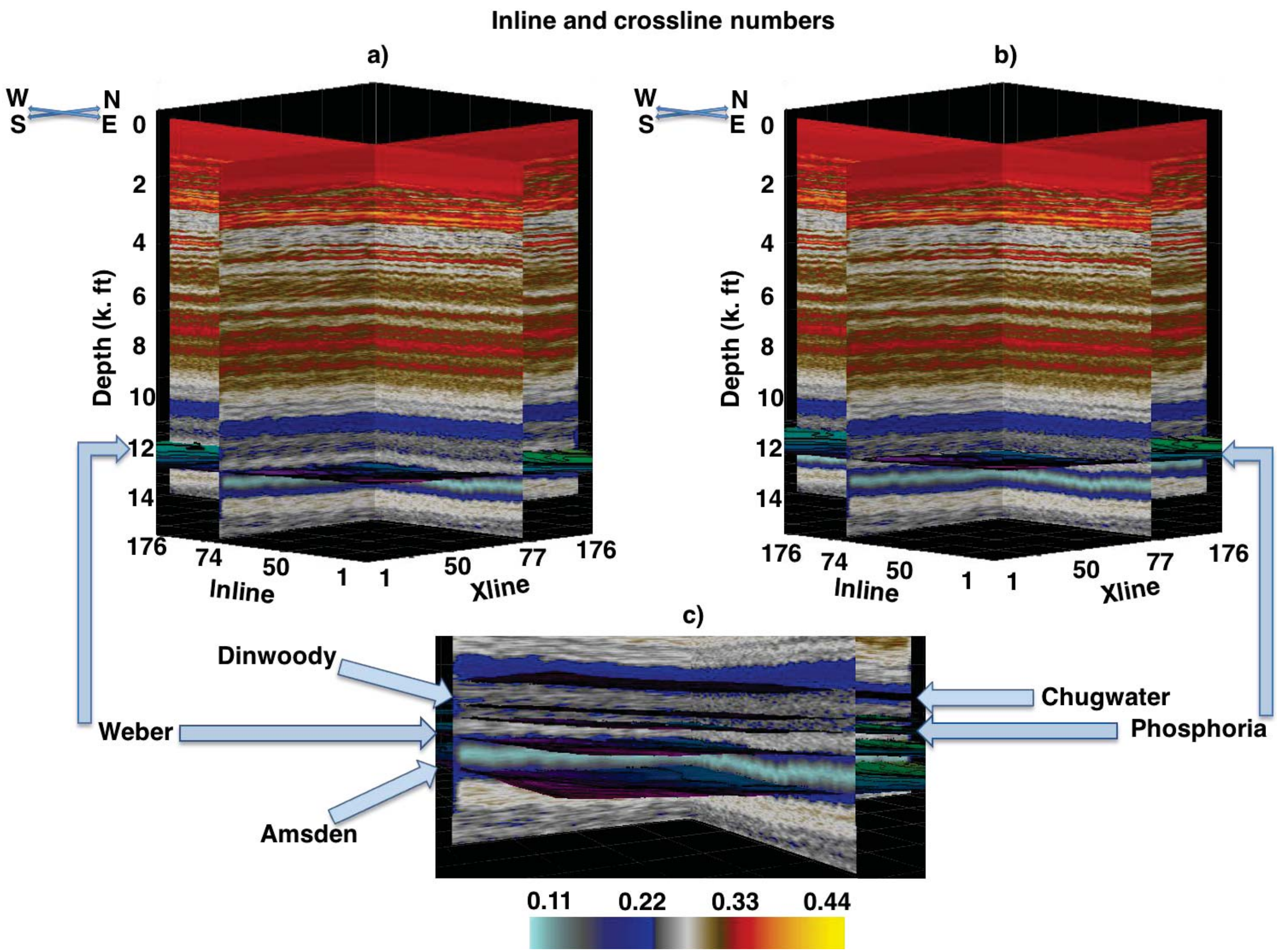
a) **Observed Stack**
b) **Real Stack**
c) **Synthetic Stack**

Z-axis: Time in s

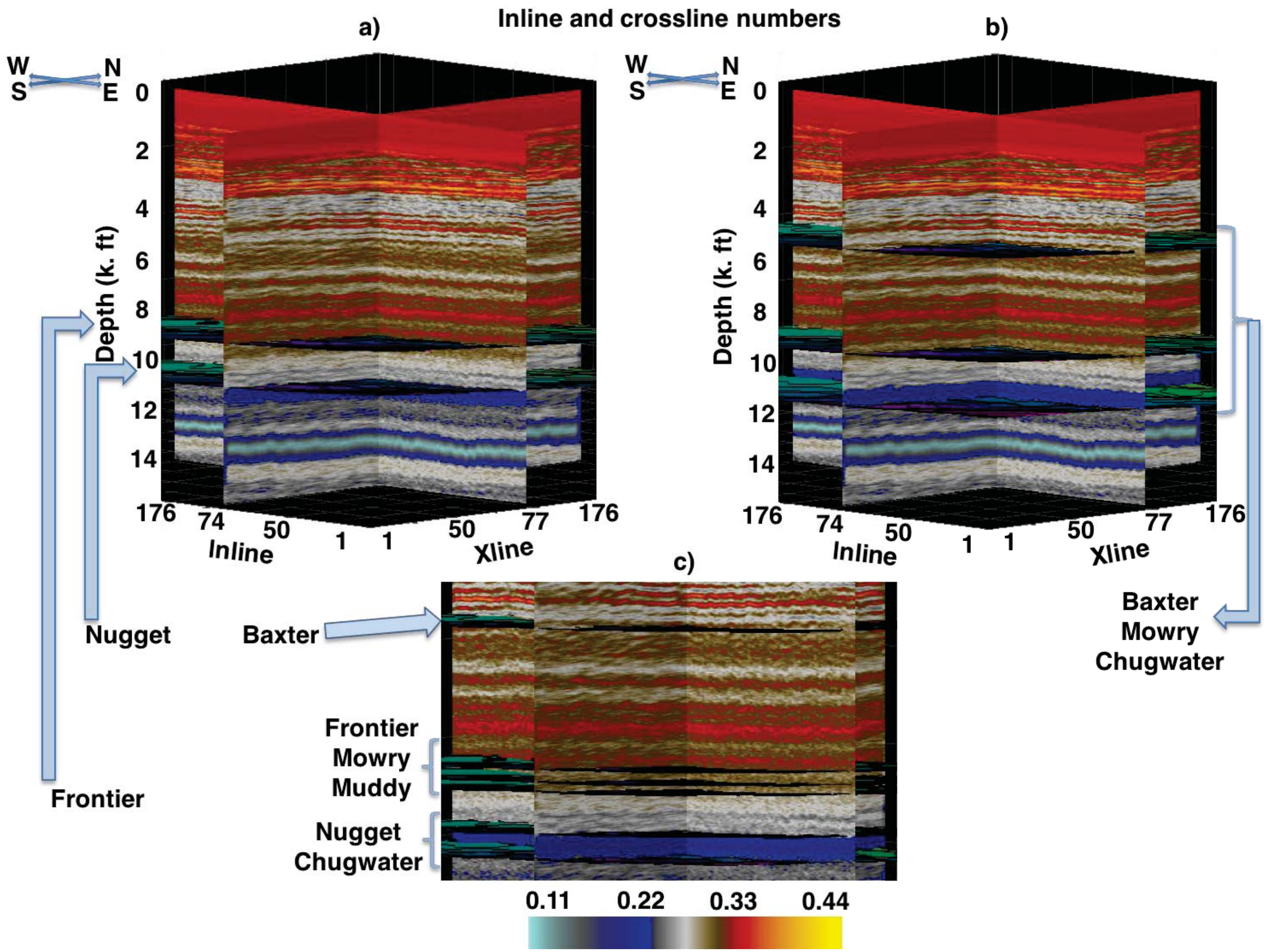




Inline and crossline numbers
a)
b)
c)
W
N
S
E
Depth (k. ft)
0
2
4
6
8
10
12
14
176
74
50
1
Inline
1
50
77
176
Xline
Madison
Amsden
Base Madison
0.11
0.22
0.33
0.44



Inline and crossline numbers
a)
b)
c)
W
N
S
E
Depth (k. ft)
0
2
4
6
8
10
12
14
176
74
50
1
Inline
1
50
77
176
Xline
Dinwoody
Weber
Amsden
Chugwater
Phosphoria
0.11
0.22
0.33
0.44



Inline and crossline numbers
a)
b)
c)
W
N
S
E
Depth (k. ft)
0
2
4
6
8
10
12
14
176
74
50
1
Inline
1
50
77
176
Xline
Frontier
Nugget
Baxter
Mowry
Chugwater
Frontier
Mowry
Muddy
Nugget
Chugwater
0.11
0.22
0.33
0.44

Conclusions

- Good overall match between observed and synthetic data and estimation of subsurface properties.

- Identification of potential storage and sealing lithologies for a future project of CO_2 sequestration.

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