Energy & Environmental Research Center (EERC)

2D SEISMIC AS AN ALTERNATIVE FOR CO_2 MONITORING IN THE NORTH DAKOTA CARBONSAFE PROJECT

2023 International Meeting for Applied Geoscience & Energy (IMAGE)

Houston, Texas

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César Barajas-Olalde,*[1], Donald C. Adams,[1], Hansel Gonzalez,[2], Mengmeng Zhang,[2]
Pablo Benítez,[2], Ryan J. Klapperich,[1], Wesley D. Peck,[1], and Panos Doulgeris,[2]

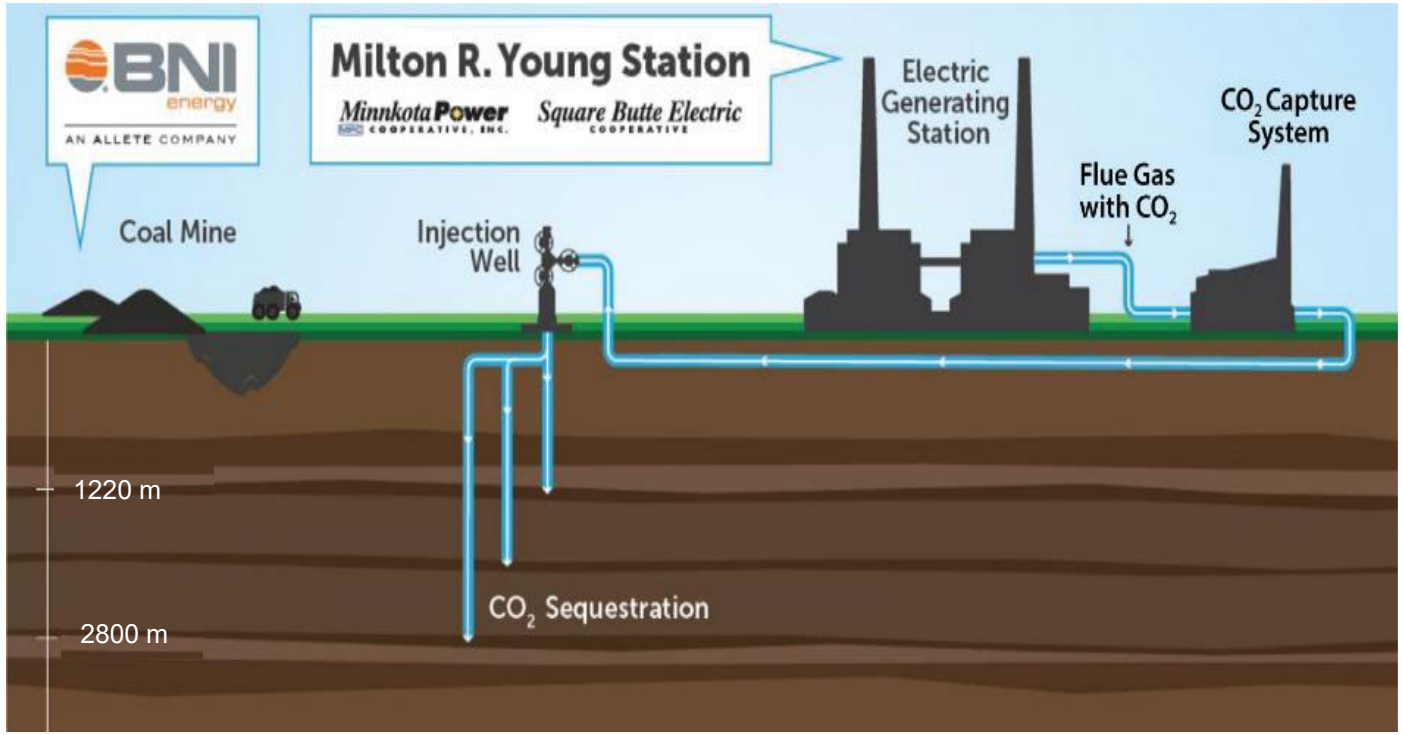
[1]Energy & Environmental Research Center

[2]Delft Inversion

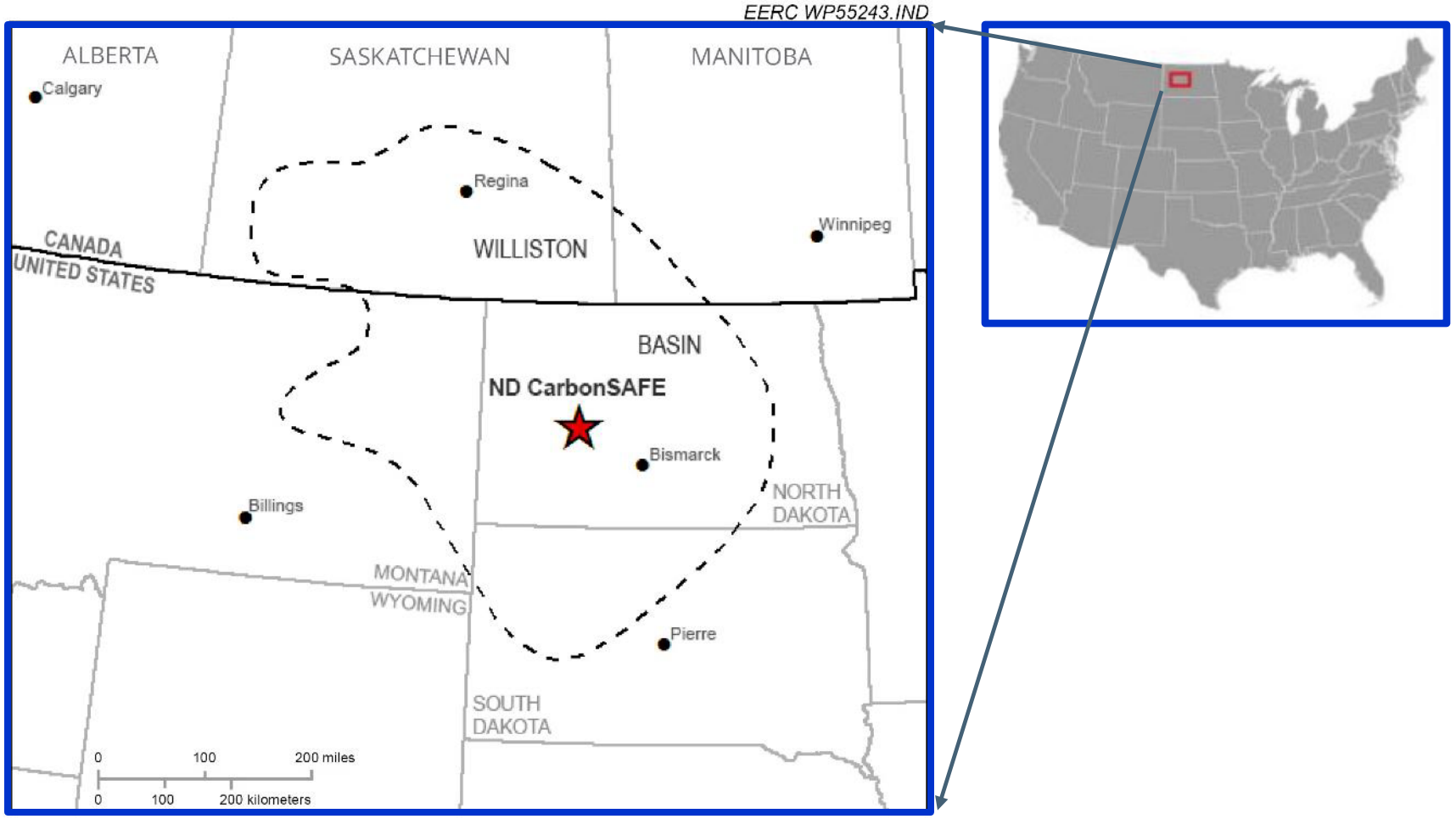
NORTH DAKOTA CARBONSAFE PROJECT

North Dakota CarbonSAFE (Carbon Storage Assurance Facility Enterprise) - carbon capture, utilization, & storage (CCUS) project

- Part of U.S. Department of Energy initiative to develop sites to store 50+ million metric tons of CO_2 from industrial sources.
- Characterization of a CO_2 storage complex near Minnkota's Milton R. Young Station (Broom Creek Fm & Deadwood Fm)
- Up to 4 million metric tons of CO_2 per year.

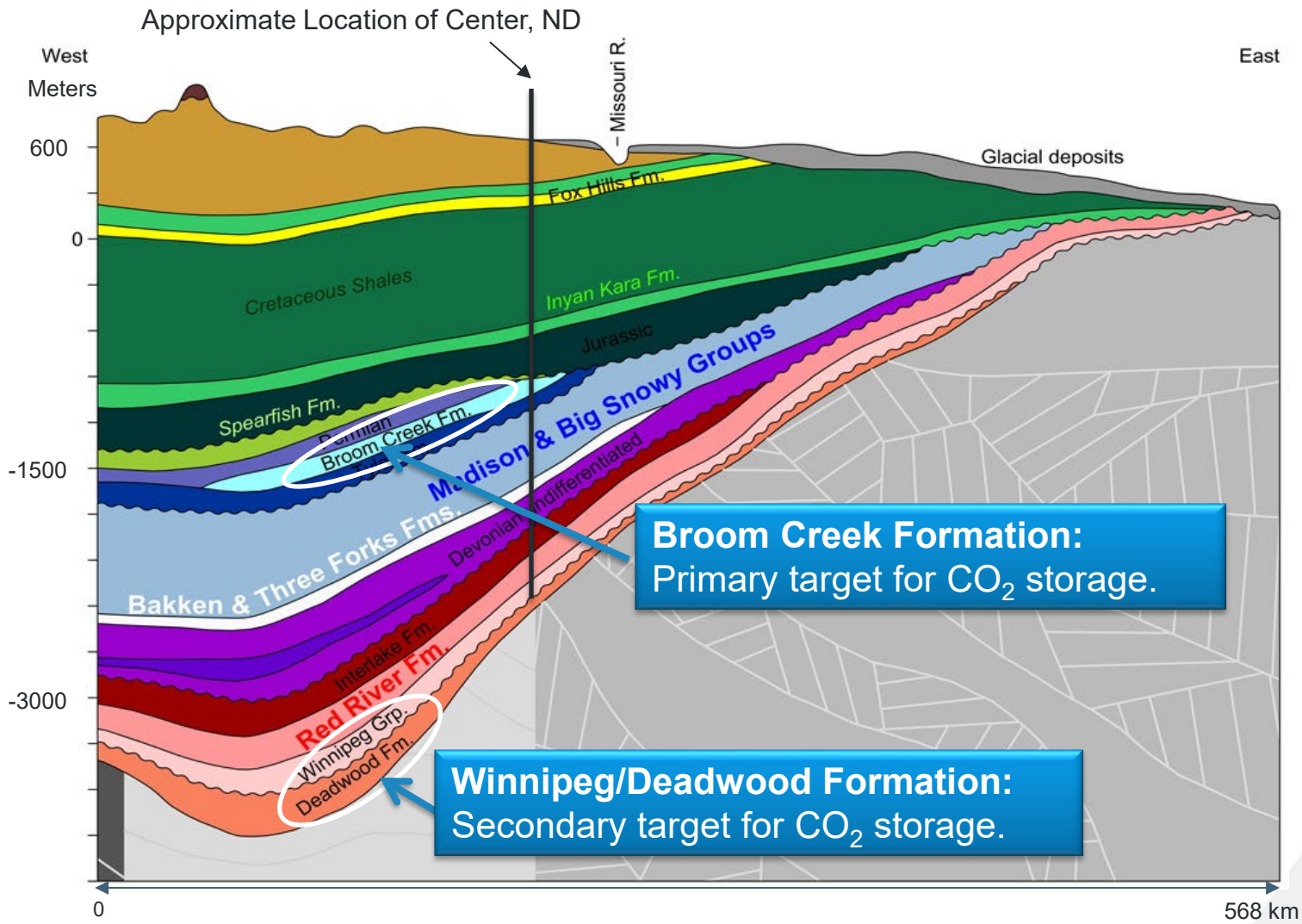


STUDY AREA


EERC WP55243.IND
ALBERTA
SASKATCHEWAN
MANITOBA
Calgary
Regina
Winnipeg
WILLISTON
CANADA
UNITED STATES
BASIN
ND CarbonSAFE
Bismarck
Billings
NORTH DAKOTA
MONTANA
WYOMING
Pierre
SOUTH DAKOTA
0 100 200 miles
0 100 200 kilometers

NORTH DAKOTA GEOLOGY & TARGET RESERVOIRS

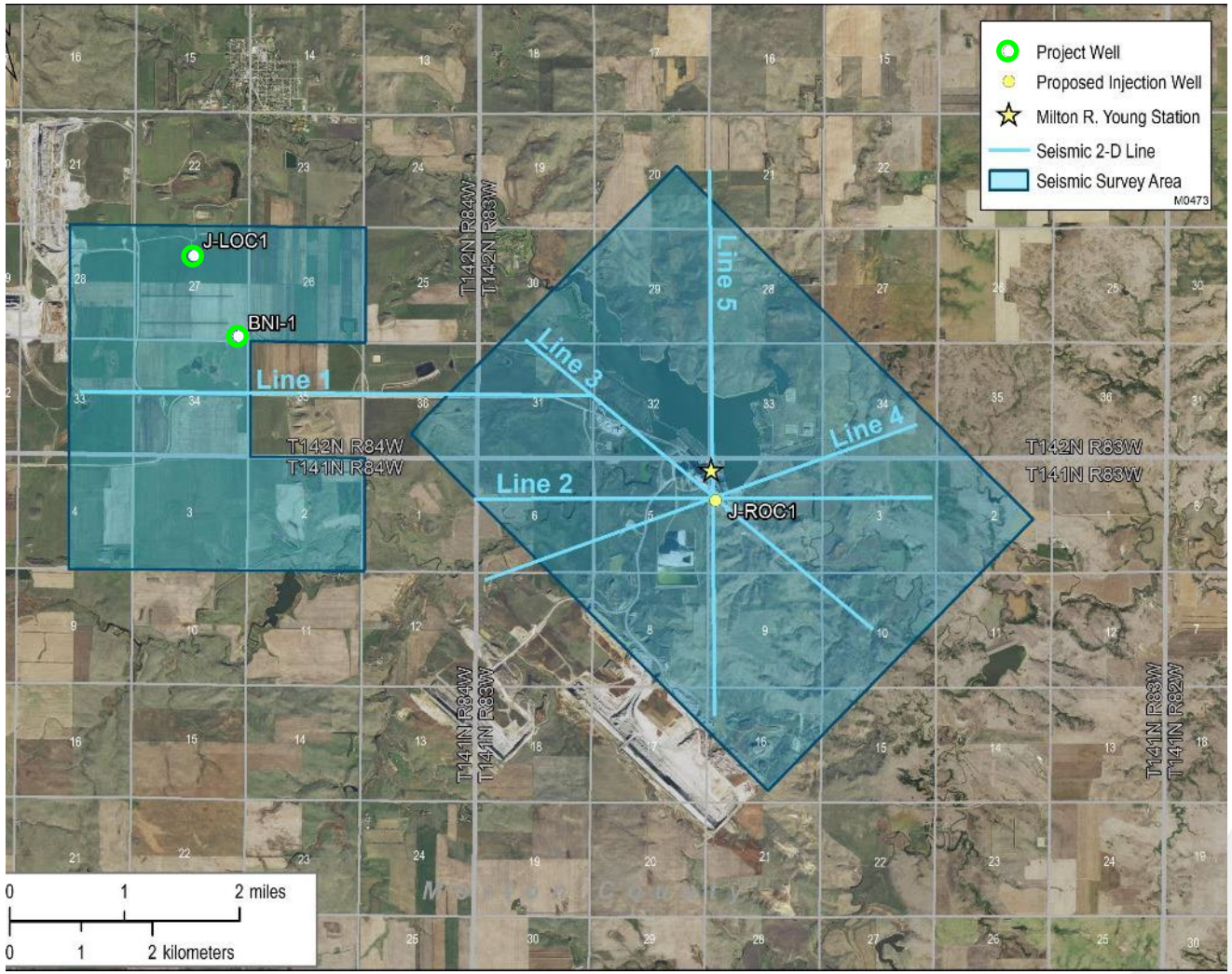
- **Broom Creek Fm**
  - Eolian & nearshore marine sandstone–carbonate cycles: sandstone, dolomite sandstone, dolostone, and anhydrite
    - Thickness in study area: ~85 m
    - Average porosity sandstone: 23 %
    - Average permeability sandstone: 222 mD
- **Deadwood Fm**
  - Marine siltstones, sandstones, & shales on top of Precambrian basement
    - Thickness in study area ~140 m
    - Porosity: sandstone (11 %), carbonate (3.7 %); shale (1.0 %–23.0 %), siltstone (0.1 %–18.0 %)
    - Permeability: sandstone (70 mD), carbonate (7.0 mD), shale (14 mD), siltstone (0.88 mD)



Modified after North Dakota Geological Survey (ndstudies.gov)

GEOPHYSICAL OBJECTIVES

- Site characterization
- Baseline data acquisition
- Feasibility study of monitoring methods



GEOPHYSICAL OBJECTIVES

- Site characterization
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2D-3D Seismic

- 3D surveys are the **standard** monitoring method
- Mature technology from intensive R&D work in the oil industry
- *Structural information & high-lateral resolution*
- Most expensive

Controlled-source electromagnetic (CSEM)

- Most of the latest technology developments from marine environments
- *Sensitive to CO_2 saturation changes*
- Moderately expensive

Microgravity

- Less popular method for CO2 monitoring
- *Sensitive to CO_2 saturation changes*
- Less expensive

GEOPHYSICAL OBJECTIVES

- Site characterization
- Baseline data acquisition
- Feasibility study of monitoring methods

2D-3D Seismic

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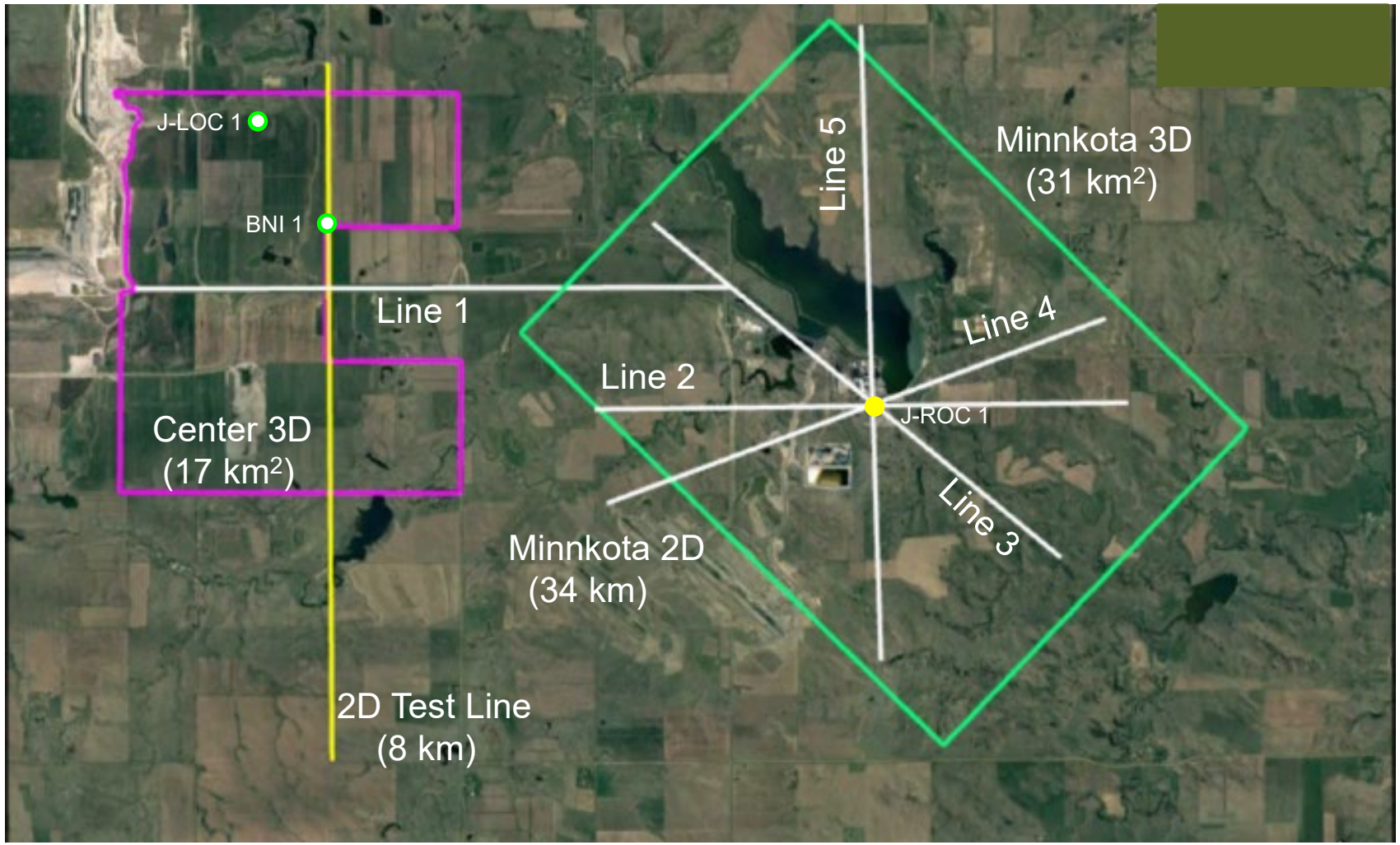
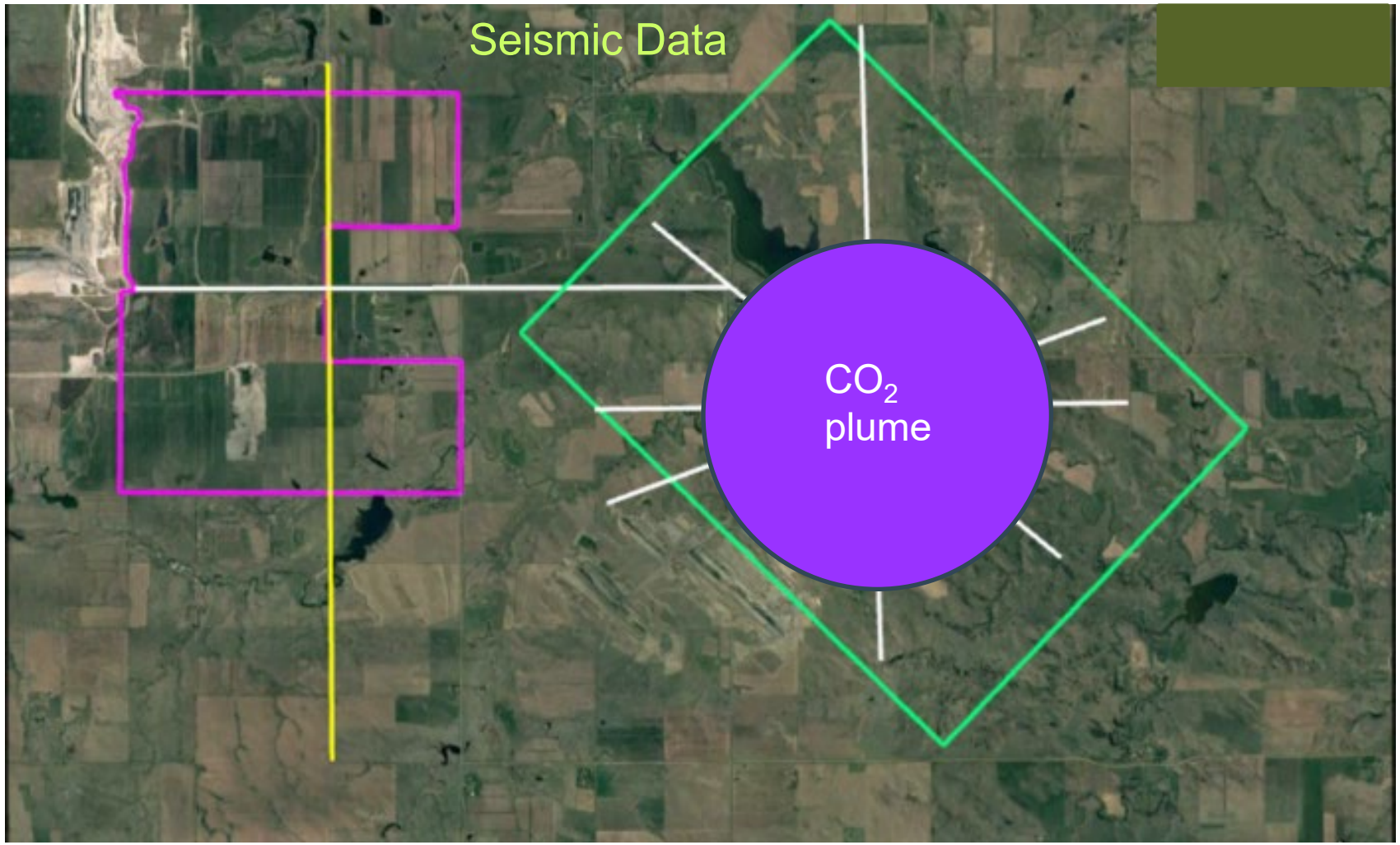
SEISMIC DATA SETS



WHY 3D AND 2D?



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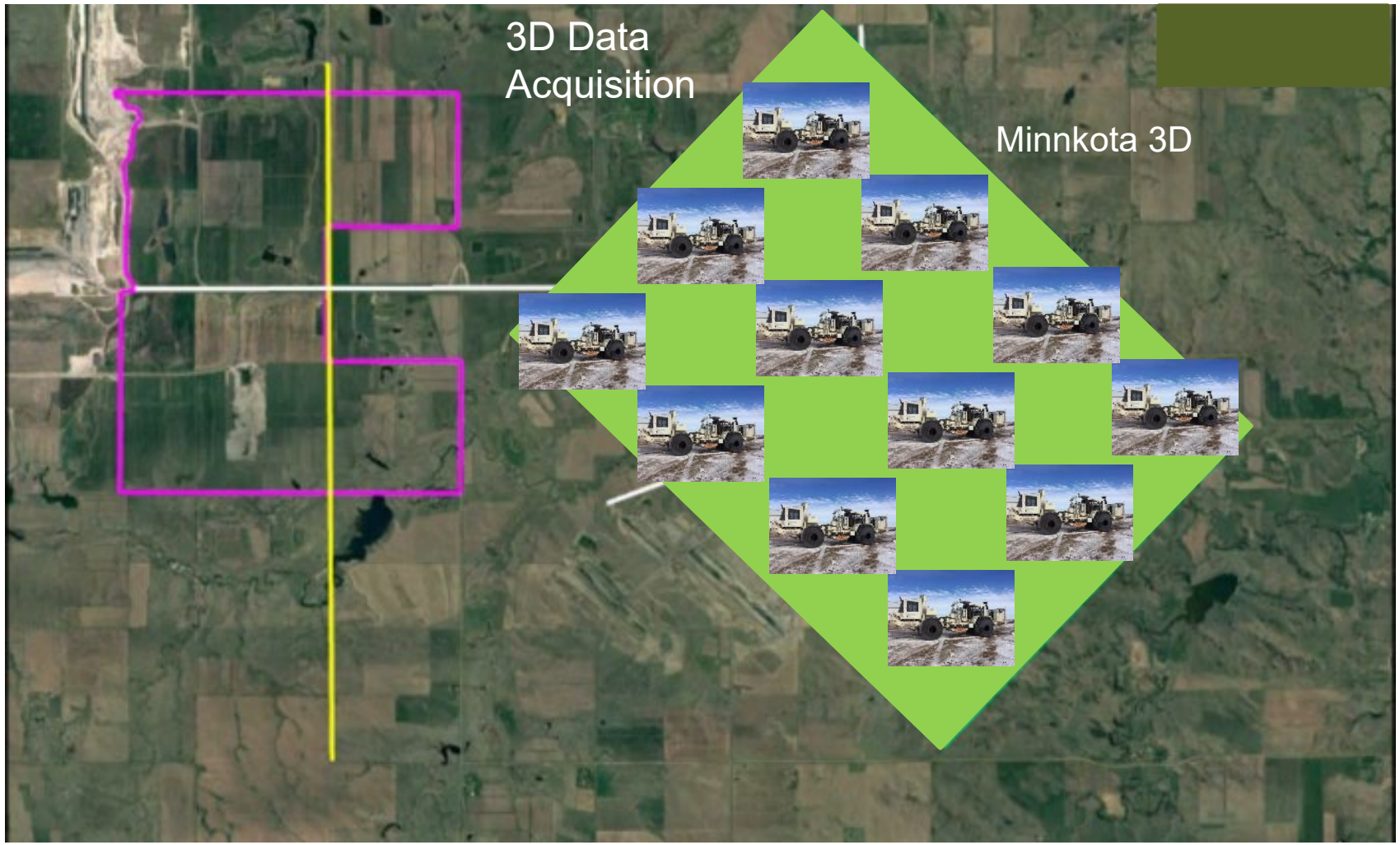

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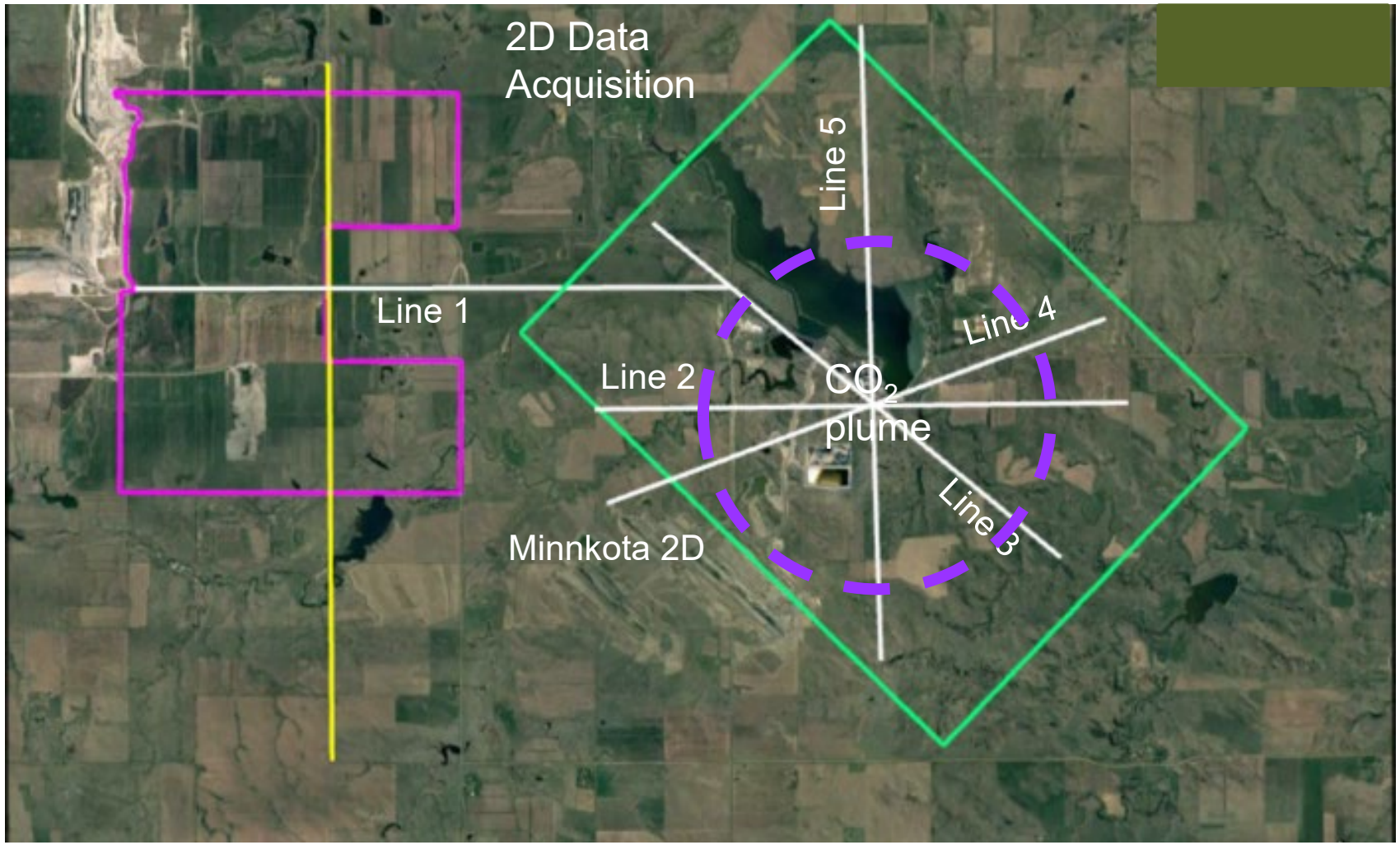
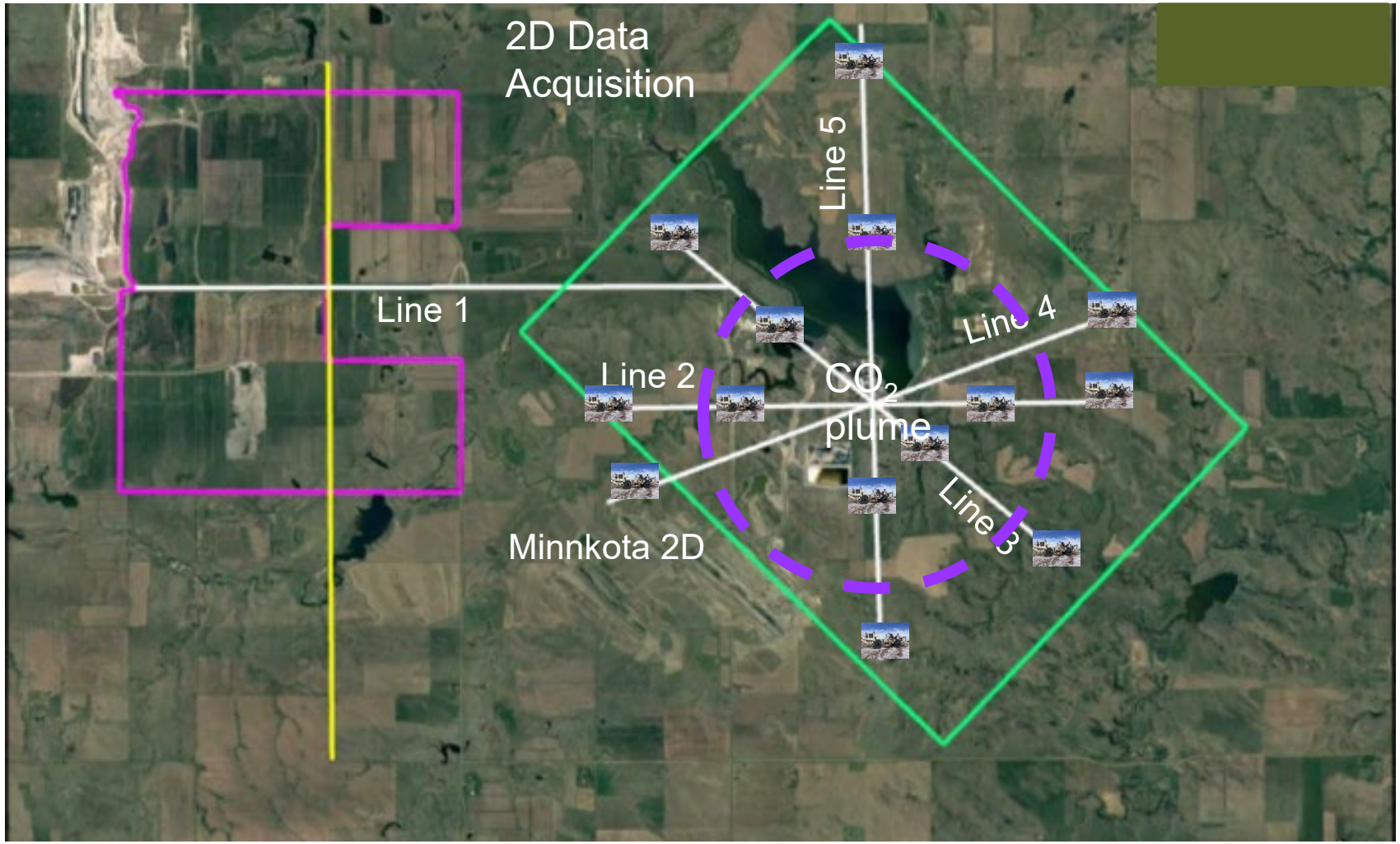

2D Data Acquisition
Line 5
Line 1
Line 4
Line 2
CO_2 plume
Line 3
Minnkota 2D

WHY 3D AND 2D?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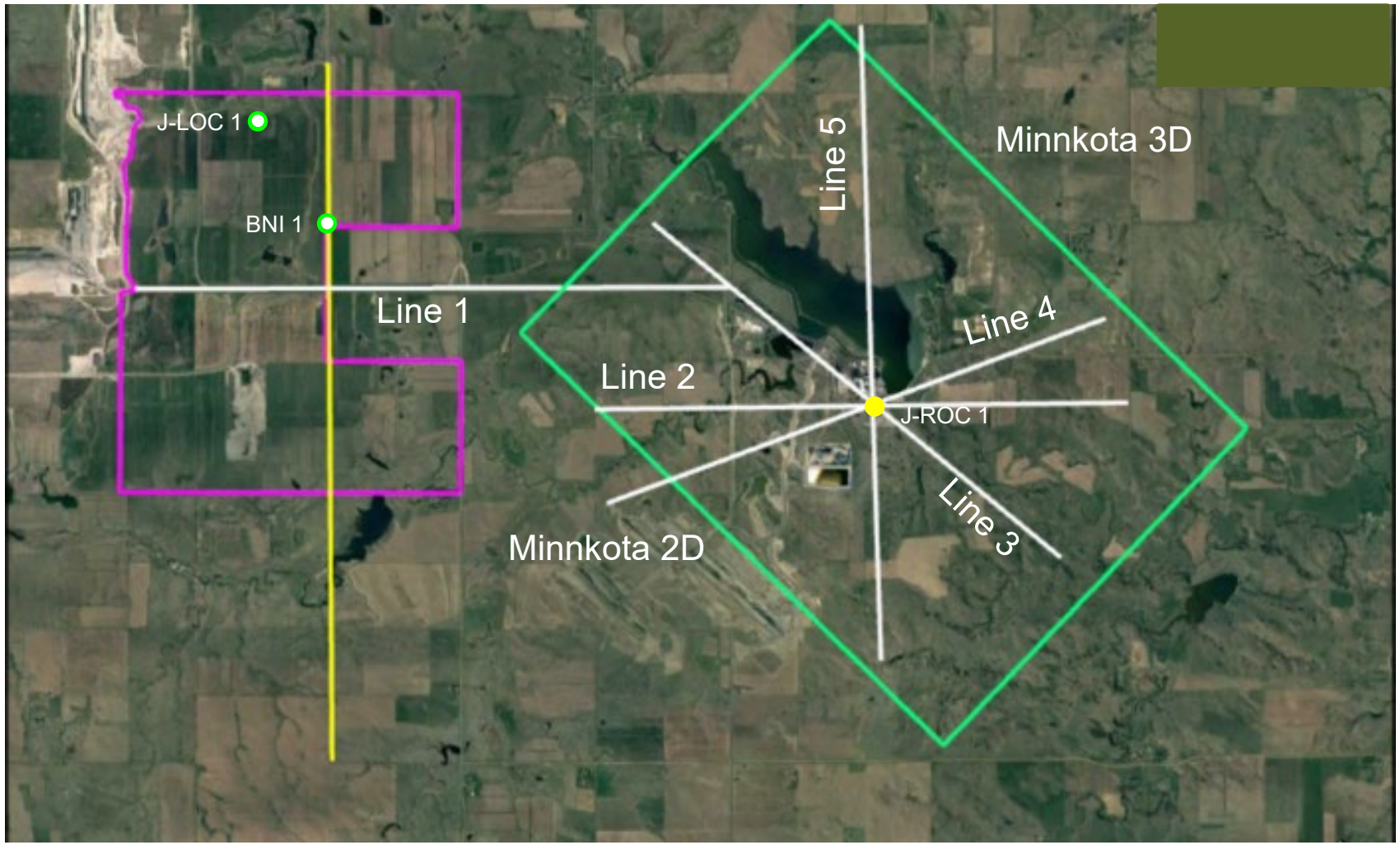
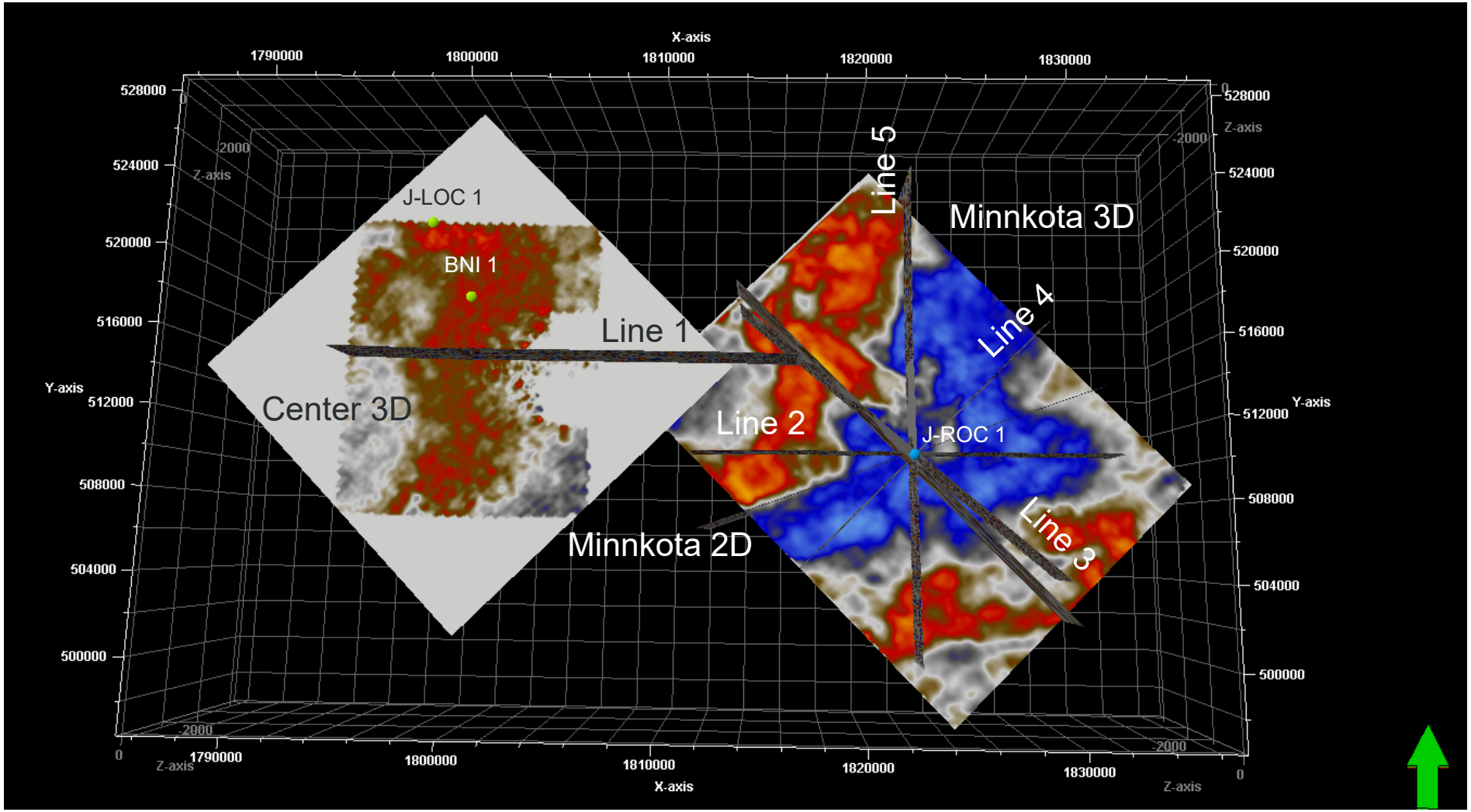
MINNKOTA 3D AND MINNKOTA 2D

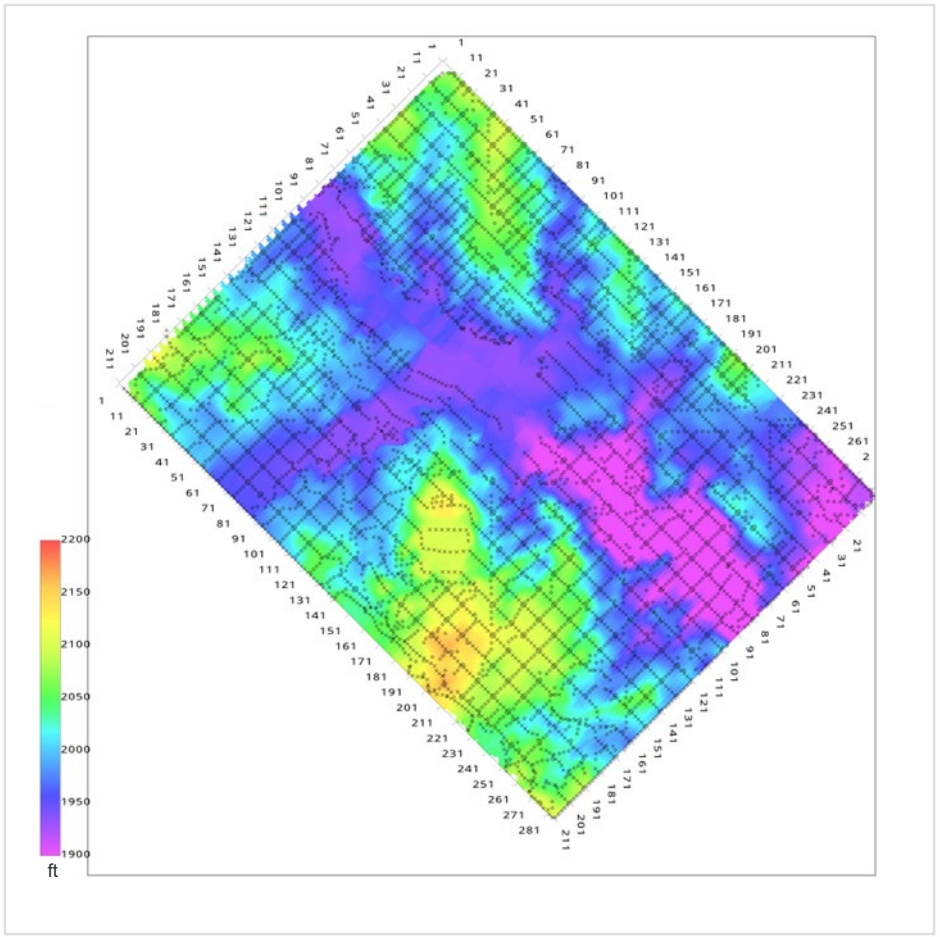


MINNKOTA 3D AND MINNKOTA 2D

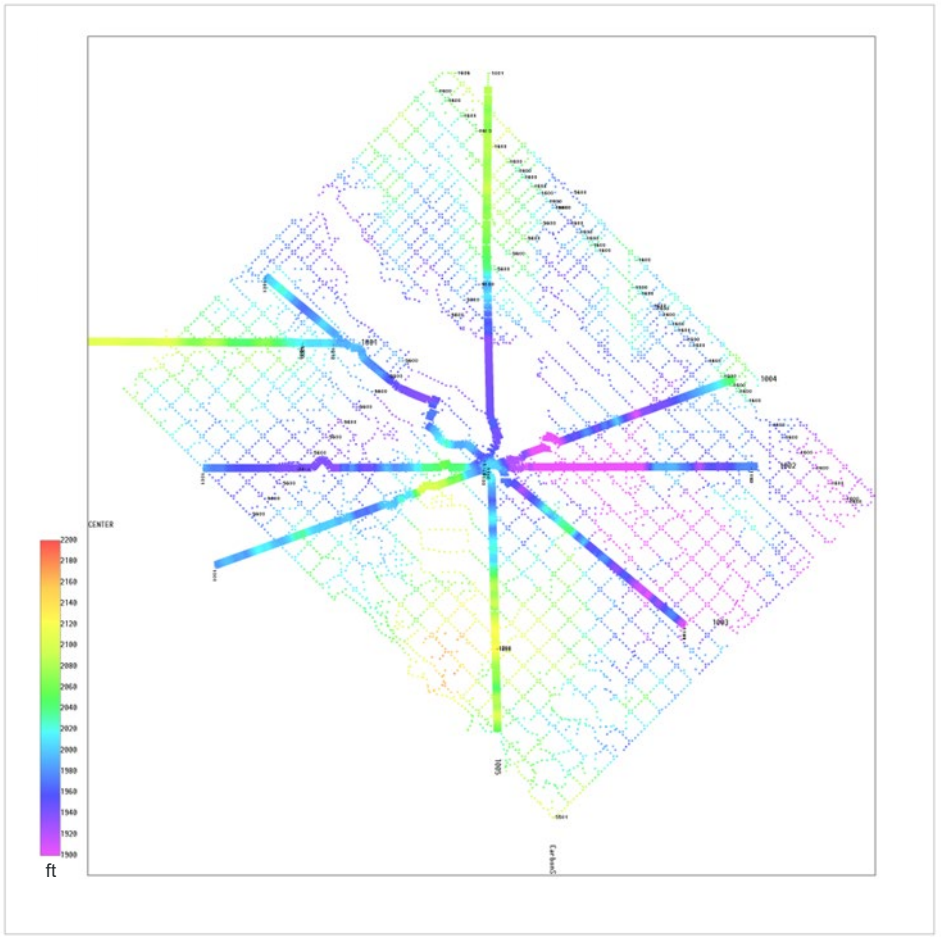


ELEVATION

Minnkota 3D



Minnkota 2D

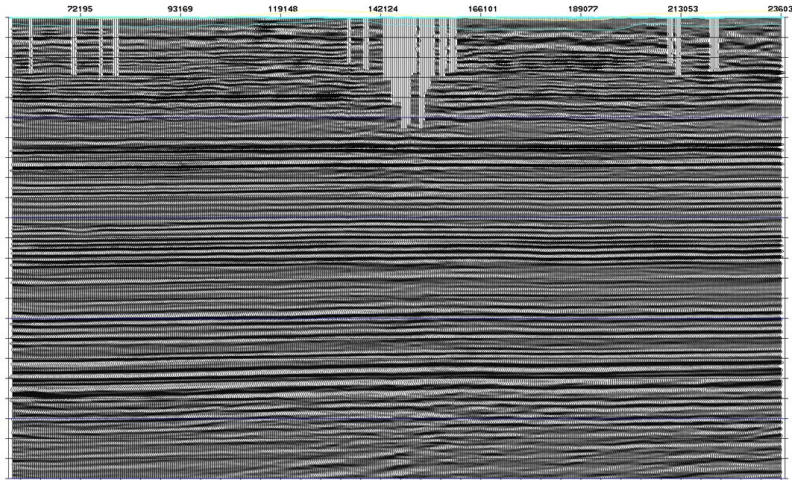


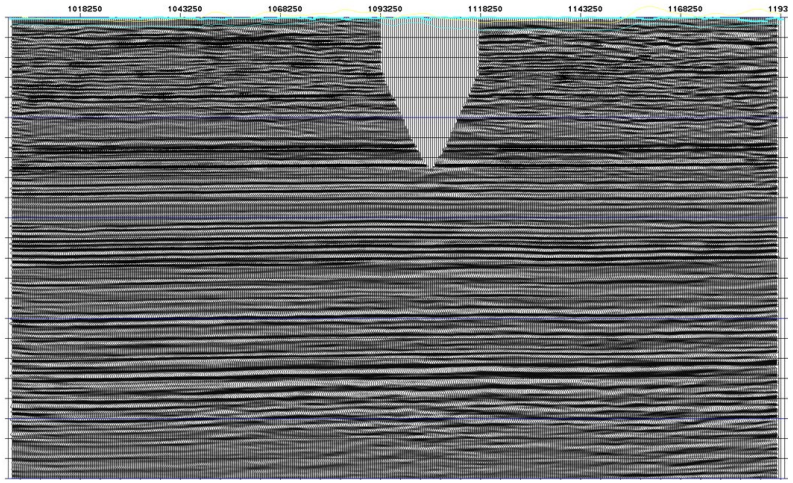
PRESTACK TIME MIGRATION

Minnkota 3D

Minnkota 2D

Extracted Line 2

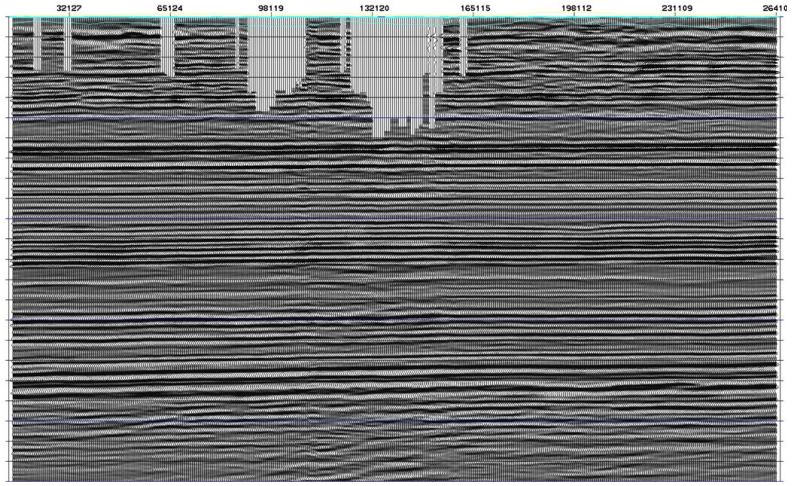


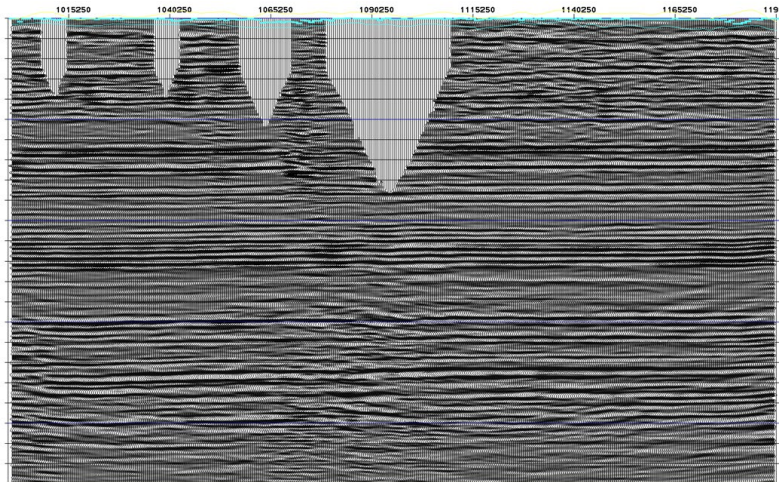


Line 2

BC

Extracted Line 3





Line 3

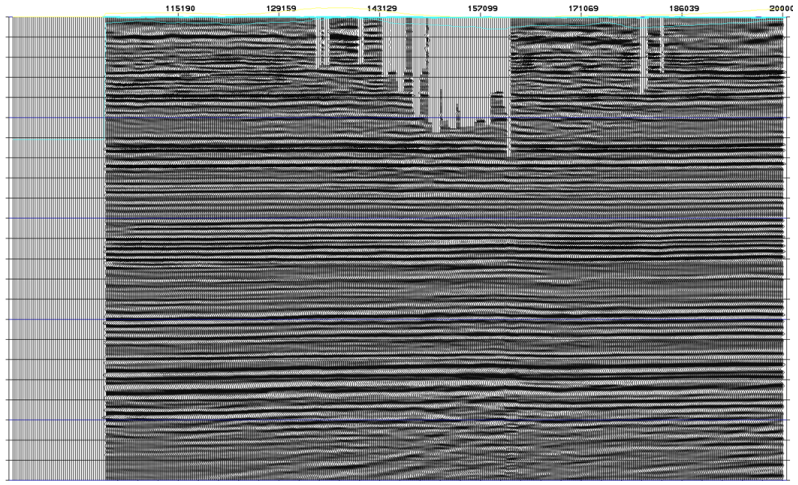
BC

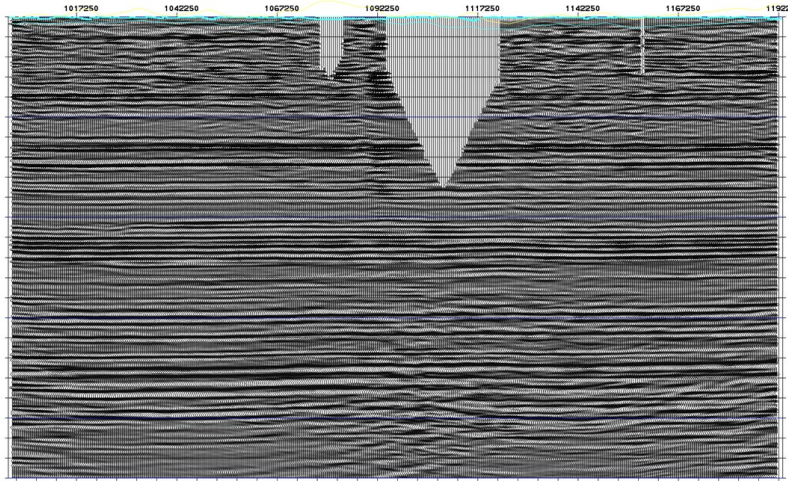
PRESTACK TIME MIGRATION

Minnkota 3D

Minnkota 2D

Extracted Line 4

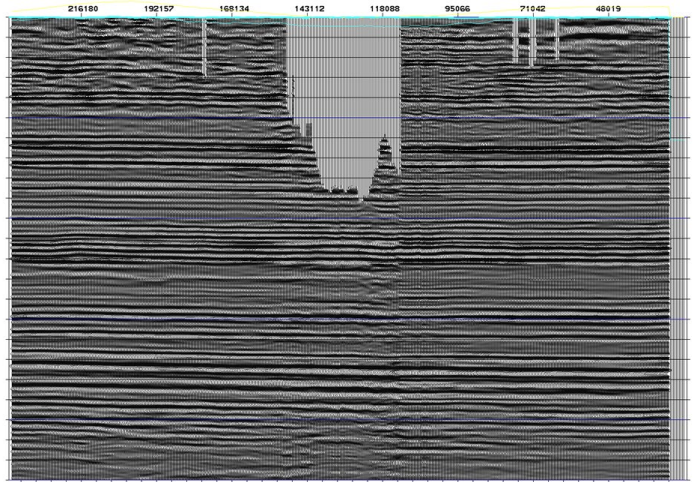


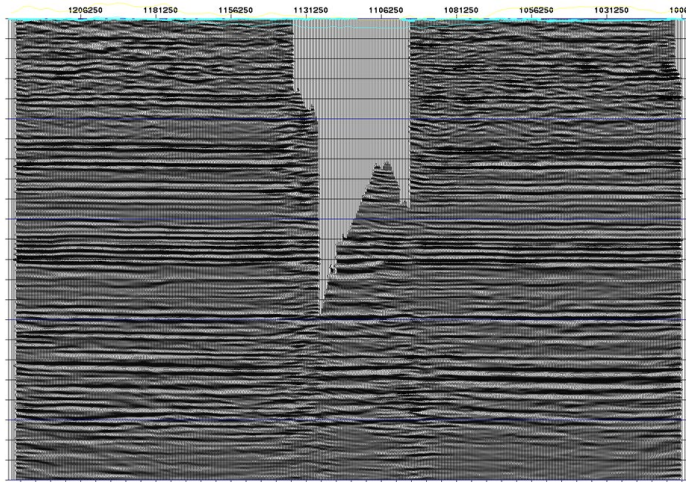


Line 4

BC

Extracted Line 5

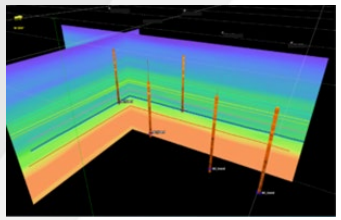


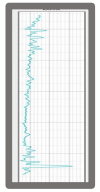


Line 5

BC

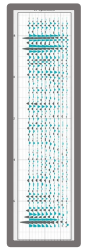
WEB-AVO INVERSION TO ESTIMATE ROCK PROPERTIES

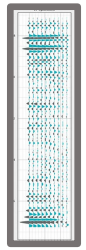




Baseline

Monitor





Simultaneous

Incident field (in background)

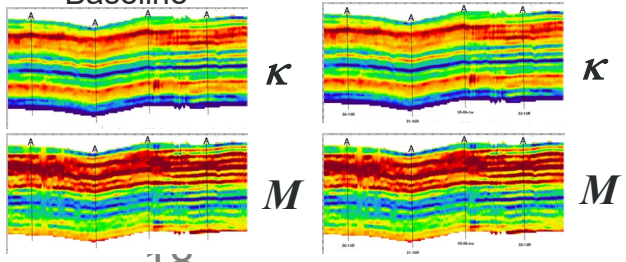
Migrated seismic gather

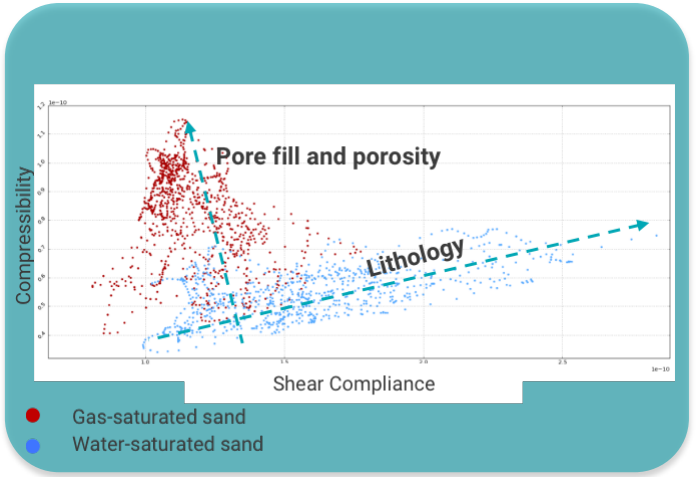
AVO inversion

Elastic reservoir properties

Use wave-equation to add higher order of scattering

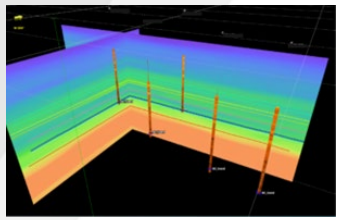
Updated total field

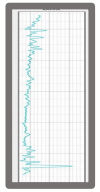




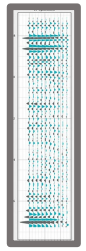
- Separation of lithology from saturation effects

WEB-AVO INVERSION TO ESTIMATE ROCK PROPERTIES





Baseline



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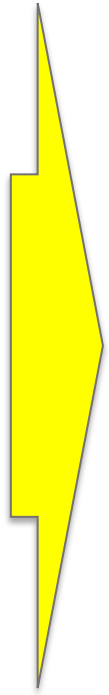
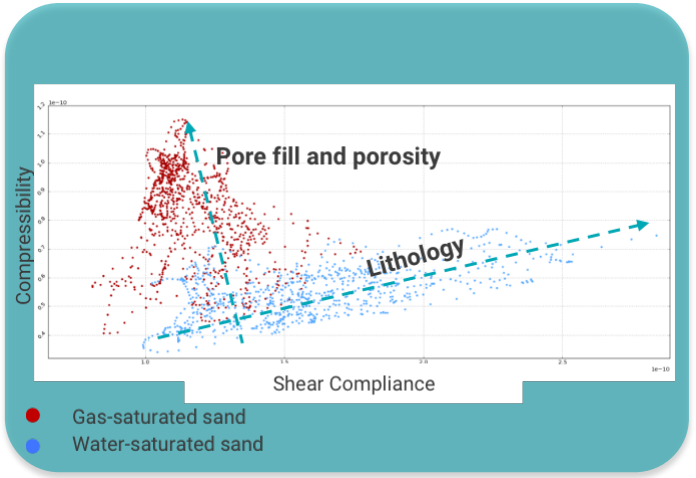
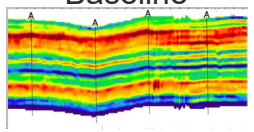




Baseline



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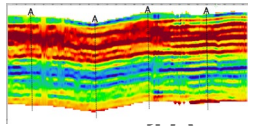
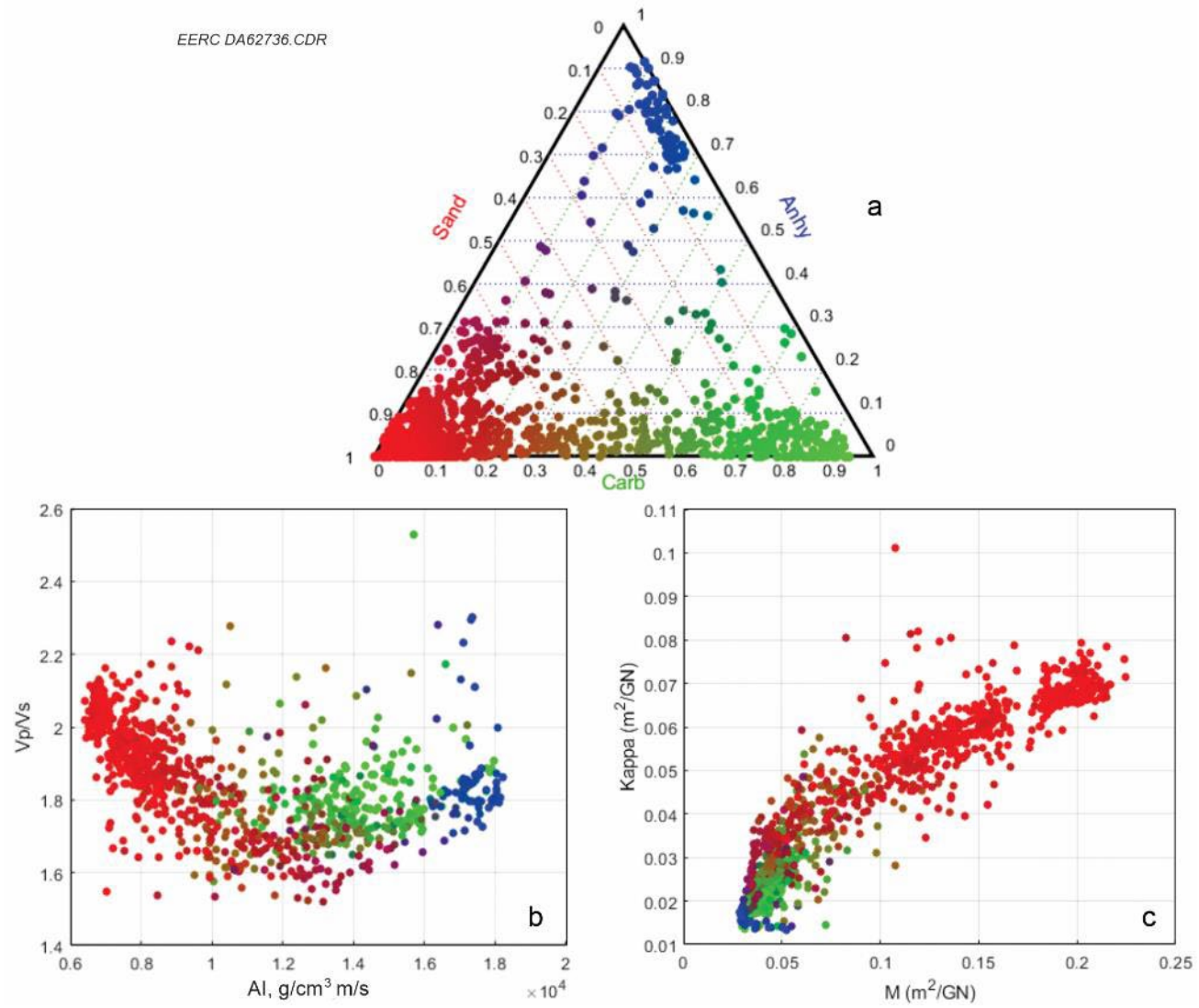


M

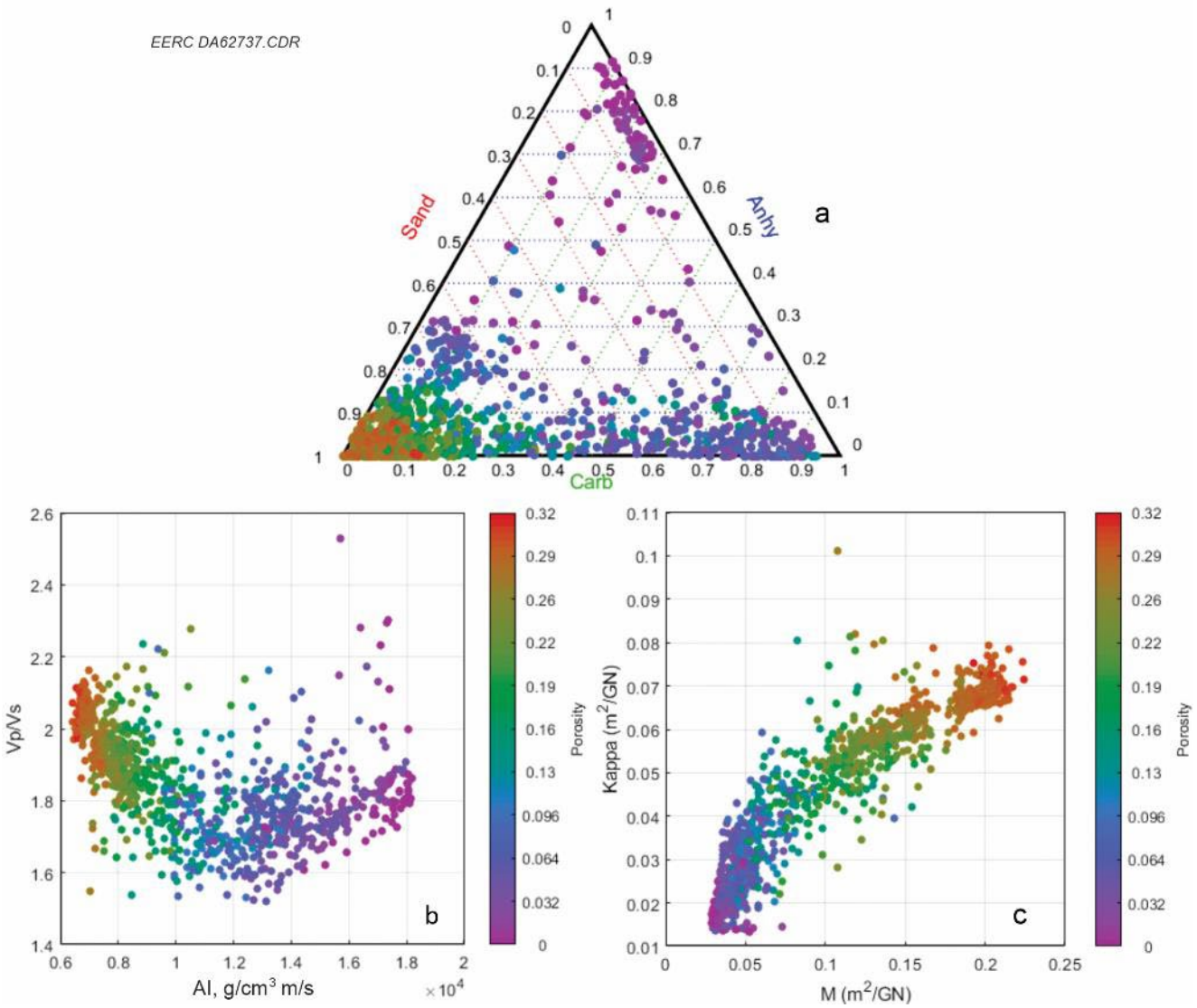
- Separation of lithology from saturation effects

CROSSPLOT ANALYSIS OF BROOM CREEK



Red: Sand
Green: Carbonate
Blue: Anhydrite

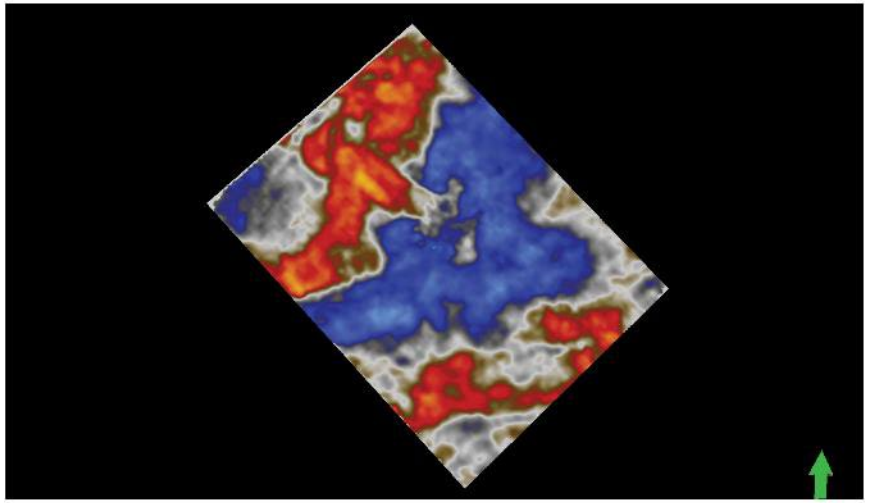
CROSSPLOT ANALYSIS OF BROOM CREEK

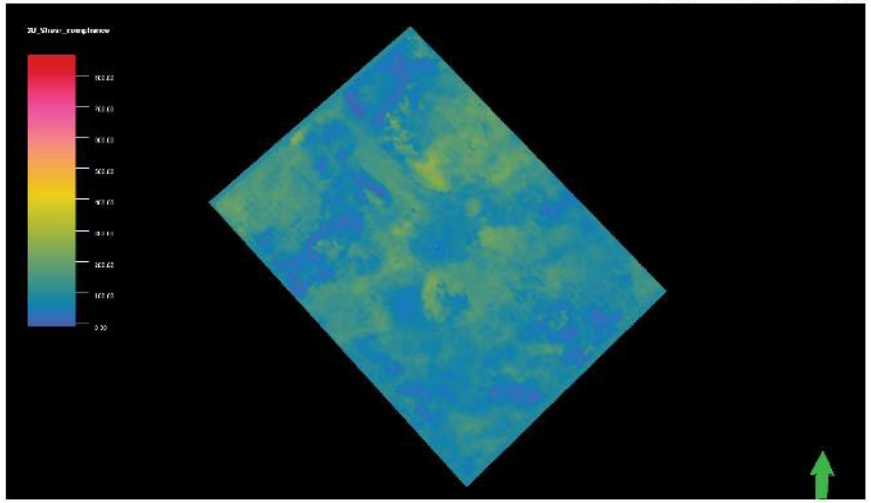


MINNKOTA 3D – WEB AVO RESULTS

EERC CBO63612.AI

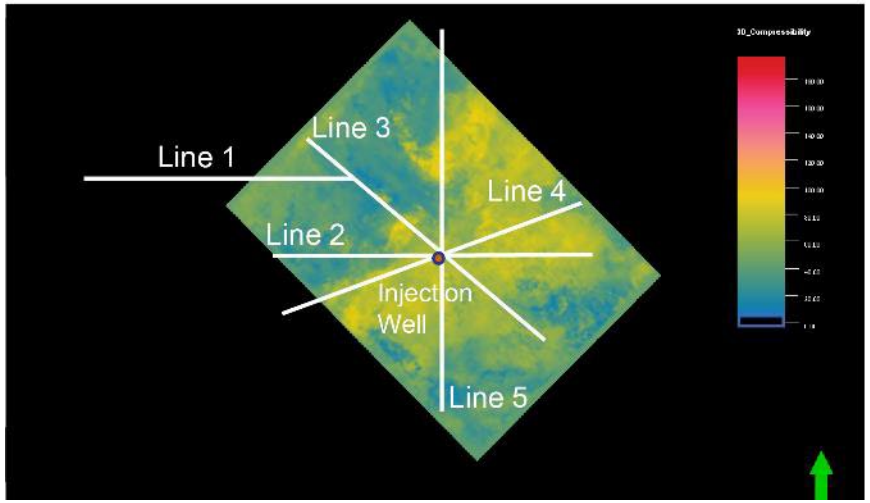
PSTM

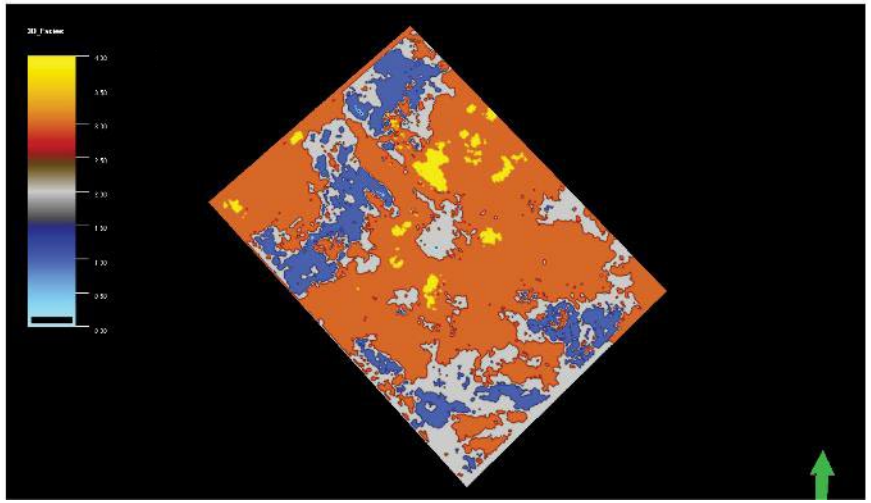




Shear Compliance (M)

Compressibility (κ)

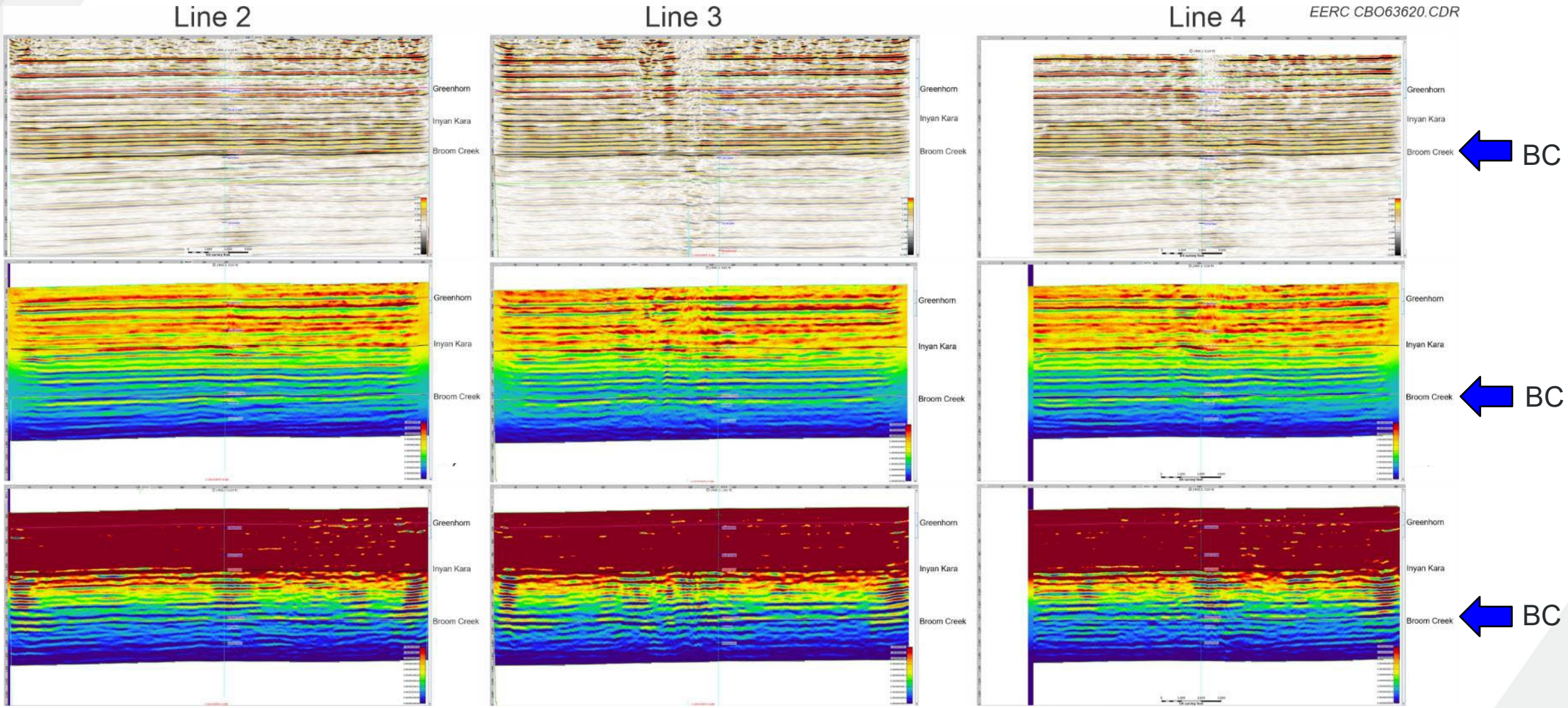




Estimated Facies

- Anhydrite (blue)
- Carbonates (gray)
- Sands (red)
- Shales (yellow)

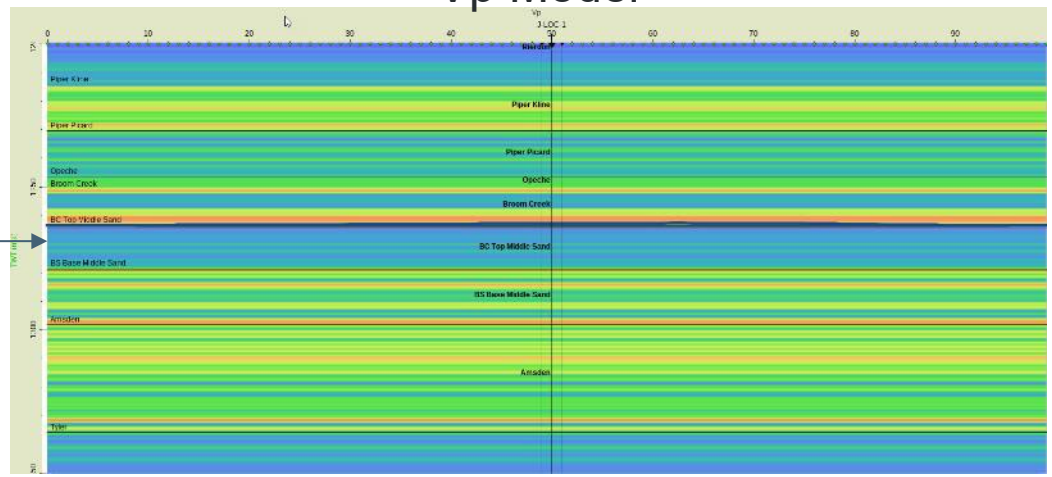
MINNKOTA 2D – WEB AVO RESULTS



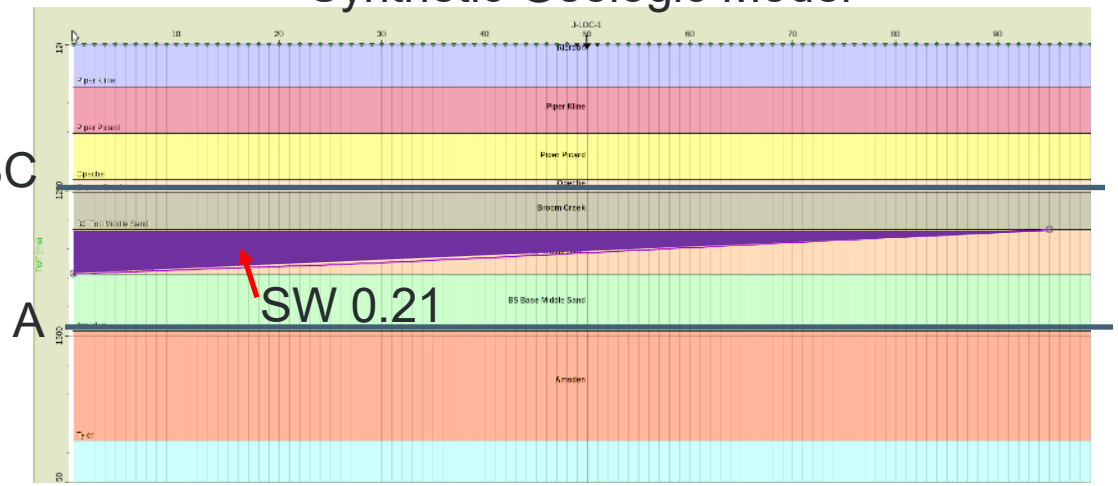
2D SEISMIC MODELING: CO_2 IN BROOM CREEK

INPUT

Vp Model

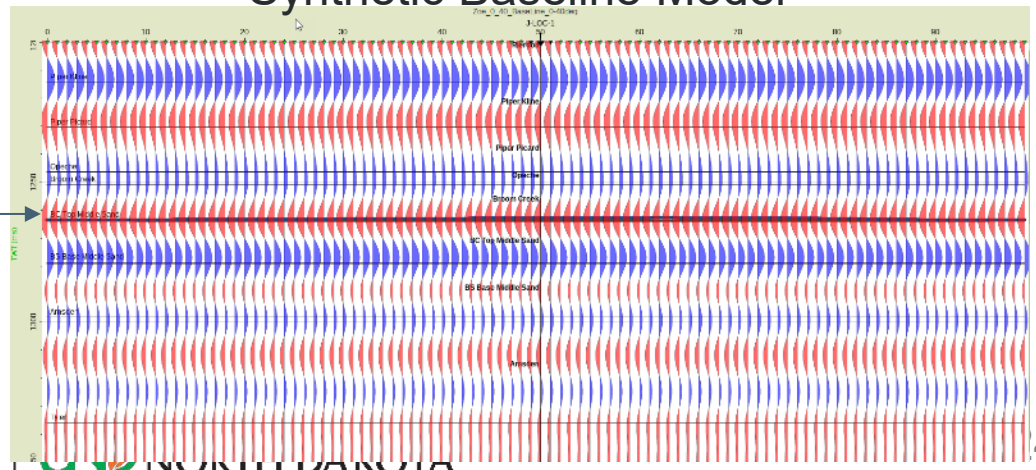


Synthetic Geologic Model

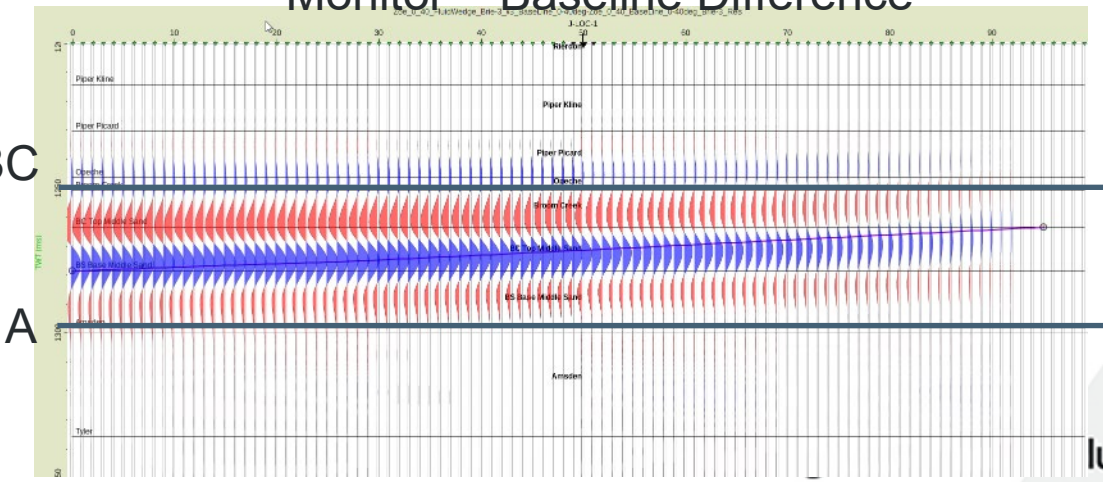


OUTPUT

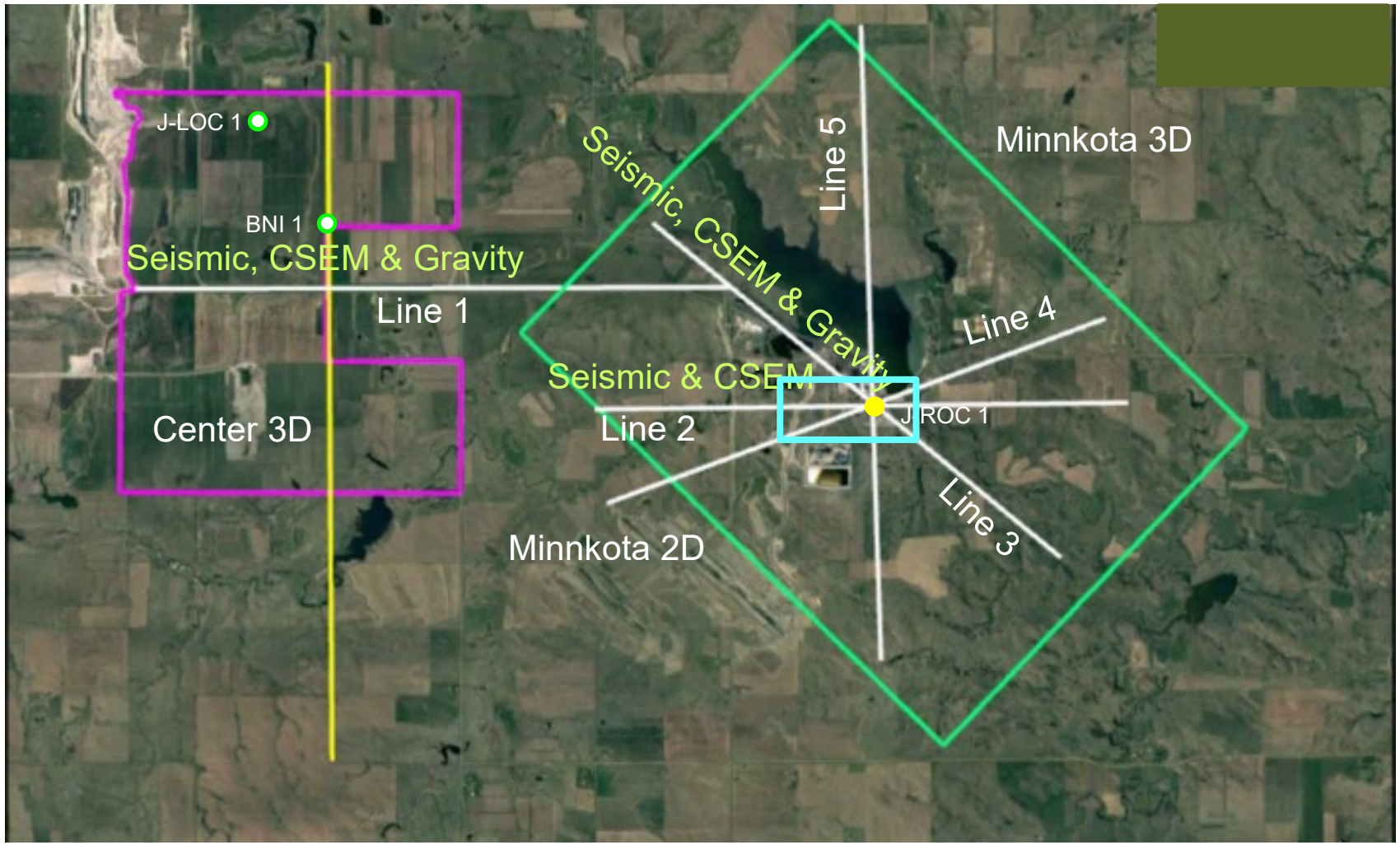
Synthetic Baseline Model



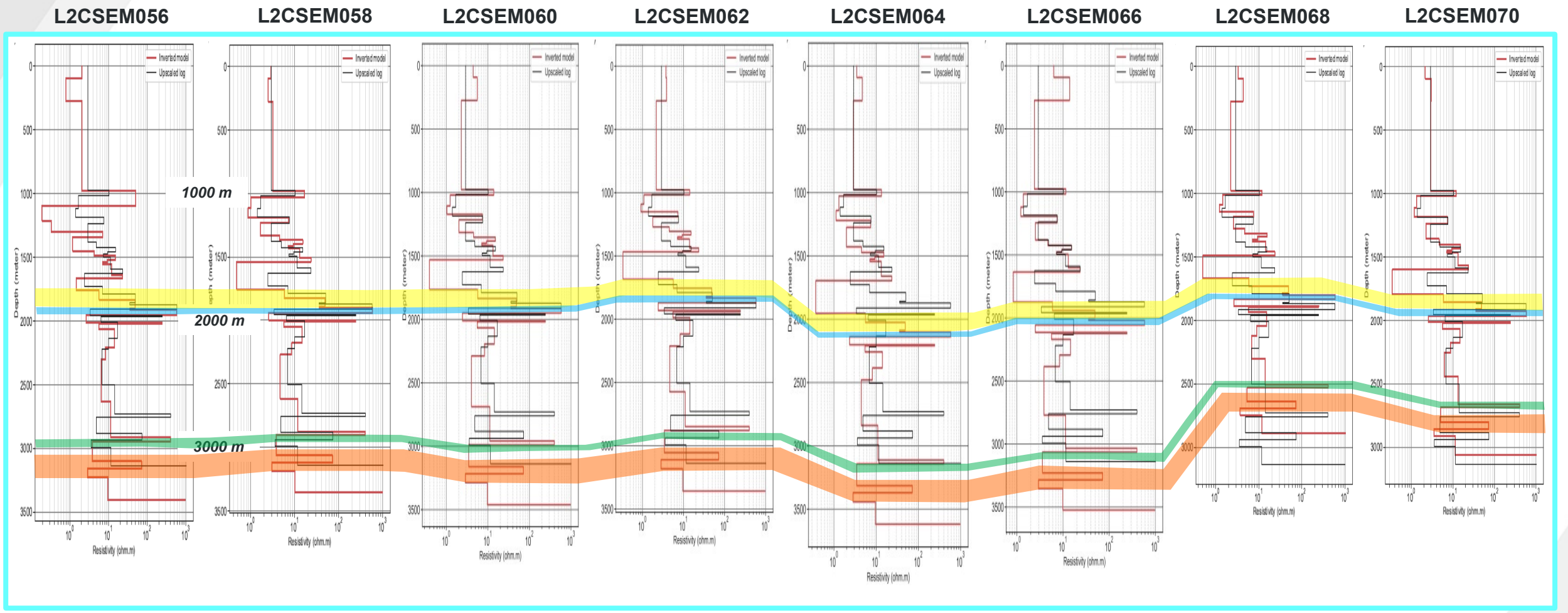
Monitor – Baseline Difference



GEOPHYSICAL DATA SETS



CSEM BASELINE 1D INVERSION RESULTS (LINE 2)



SUMMARY AND CONCLUSIONS

- Encouraging WEB-AVO results similar to 3D data were obtained using 2D data.
  - Extensive seismic data conditioning was required to obtain high-quality 3D and 2D WEB-AVO compressibility and shear compliance.
  - High resolution of 3D WEB-AVO compressibility and shear compliance.
  - The facies estimated based on WEB-AVO are compatible with the geological interpretation of data available in the study area.
  - Future 3D and 2D CO_2-monitoring scenarios should be handled well with the WEB-AVO technology.
    - Compressibility is highly sensitive to the time-lapse softening and hardening signature.
    - Shear compliance represents a good indicator of the pressure effect.
- Potential combination WEB-AVO parameters from 2D surveys with CSEM time-lapse results to assess saturation and pressure conditions due to CO_2 injection.

ACKNOWLEDGMENTS

- U.S. Department of Energy National Energy Technology Laboratory for providing the funding to conduct this research under Award No. DE-FE0031889.
- Minnkota Power Cooperative.
- BNI Coal.
- Schlumberger (Petrel).

U.S. DEPARTMENT OF ENERGY DISCLAIMER

César Barajas-Olalde
Principal Geophysicist
cbarajas@undeerc.org
701.777.5414 (phone)

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

www.undeerc.org
701.777.5000 (phone)
701.777.5181 (fax)

THANK YOU

Critical Challenges. Practical Solutions.

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Critical Challenges. Practical Solutions.