Seismic and Geosciences

Land Seismic Industry Insights Permian Basin: A look at the basics around seismic industry through past, present and future business objectives.

What the heck are we doing?

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Bruce Karr, Fairfield Geotechnologies

I have a degree in geophysical engineering from the Colorado School of Mines. My passion originates from a love of geology and being pretty good in math. Merging those two spectrums led me to a BS geophysical engineering and a minor in petroleum geology.

My career started in Saudi Arabia in the field on a land seismic crew. After 2 years I transferred to Midland Texas and have been working the Permian basin since 1990.

Much of my work centered around the basics to very technical understanding of seismic acquisition, processing and geology. Fast forward to present and seismic data is integrated into many other data sets to bring value t the Permian Basin hydrocarbon resource play.

The recent seismicity in Midland and the rest of West Texas has also put a spotlight on seismic industry. Therefore, I have very strong background in the history of what value seismic has played and the possibilities of what it could play going forward.

Me, Bruce Karr

- Colorado School of Mines graduate, 1988
  - Geophysical Engineering degree
  - Minor in Geologic engineering with petroleum geology
- Worked in Saudi Arabia out of college; 2 years
- 7 years with Halliburton
  - Middle east- in the field
  - Midland Texas- processing geophysicist
- Fairfield Geotechnologies, for 29 years
  - 3D processing expertise
    - P-wave and Multi-component
  - Managed land processing center
  - Now company wide technical adviser

What would I like for you to take from this presentation

- Seismic data is the only data volume that connects what's happening in the reservoir between wells. NO other data samples the full volume subsurface.

- Seismic data identifies, measures and can be integrated into geology and reservoir characterization.

- The evolution of the seismic industry has changed its purpose from………

Exploration to Exploitation

Seismic industry adds value through better located wells in better reservoir rock with less cost

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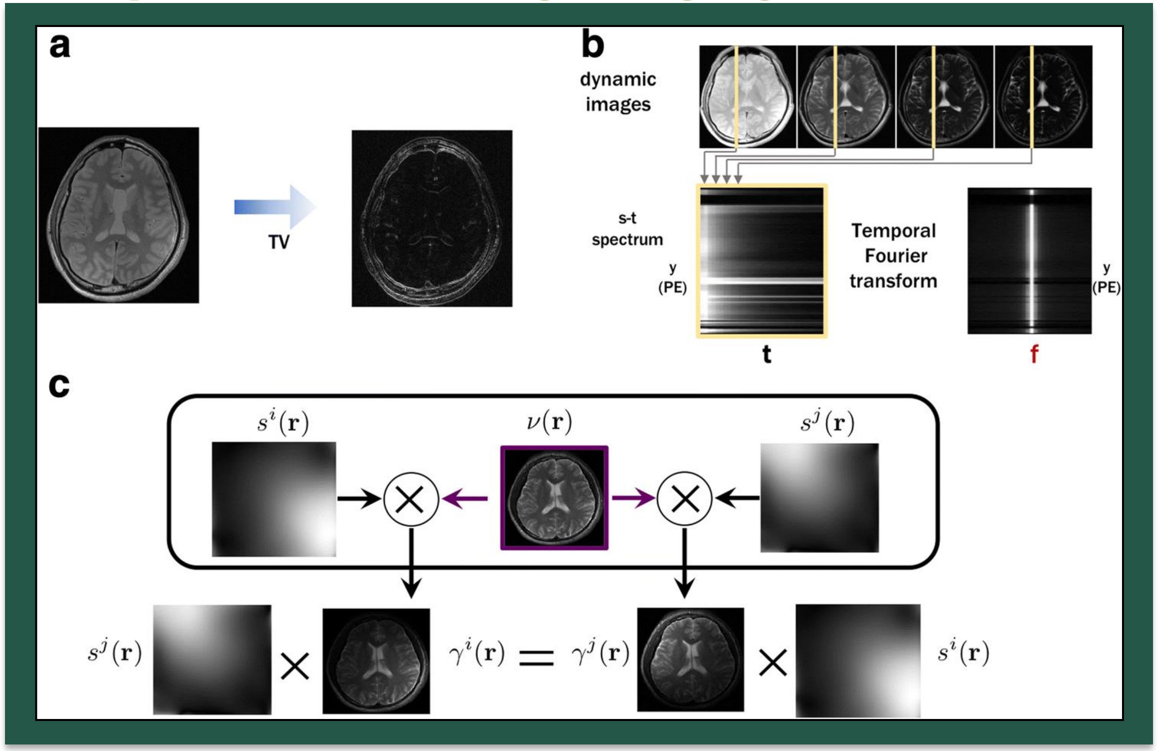
Technology Focus

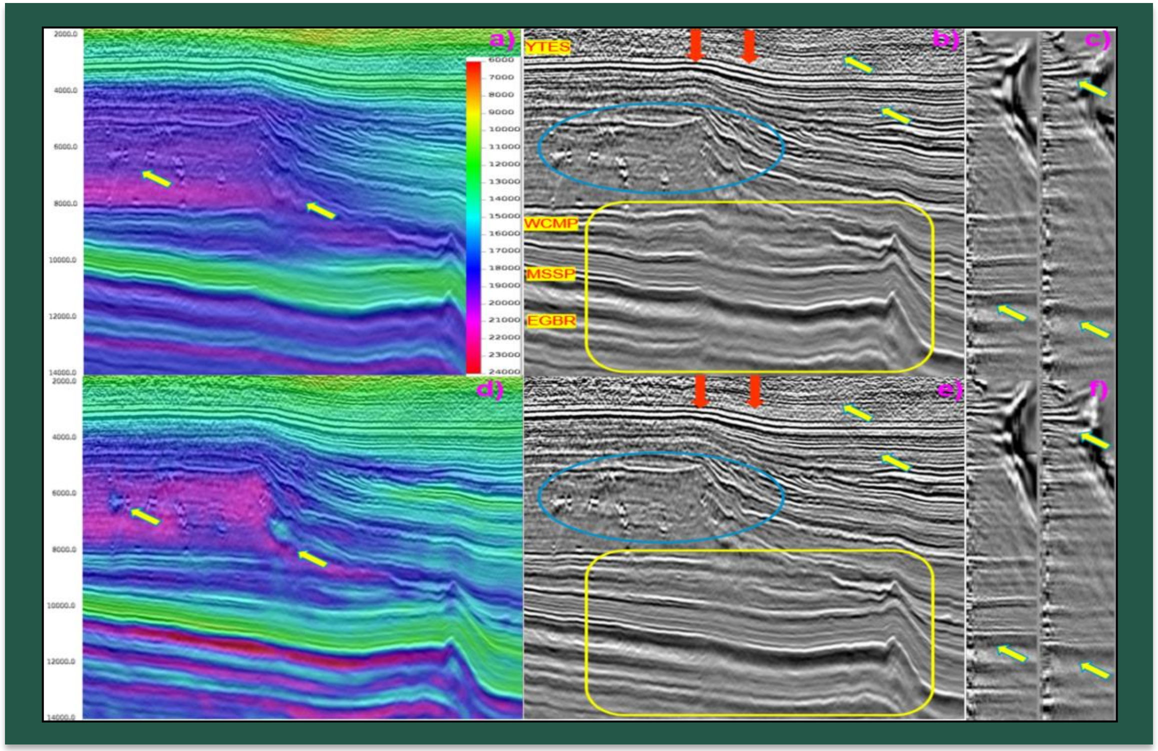
Compressive Sensing Imaging



Various types of sparsity in MRI. (**a**) Sparsity from Spatial domain redundancy, (**b**) Sparsity from temporal redundancy, and (**c**) sparsity from multi-channel redundancy

Ye, J.C. Compressed sensing MRI: a review from signal processing perspective. *BMC biomed eng* **1**, 8 (2019). https://doi.org/10.1186/s42490-019-0006-z

Full-Waveform Inversion



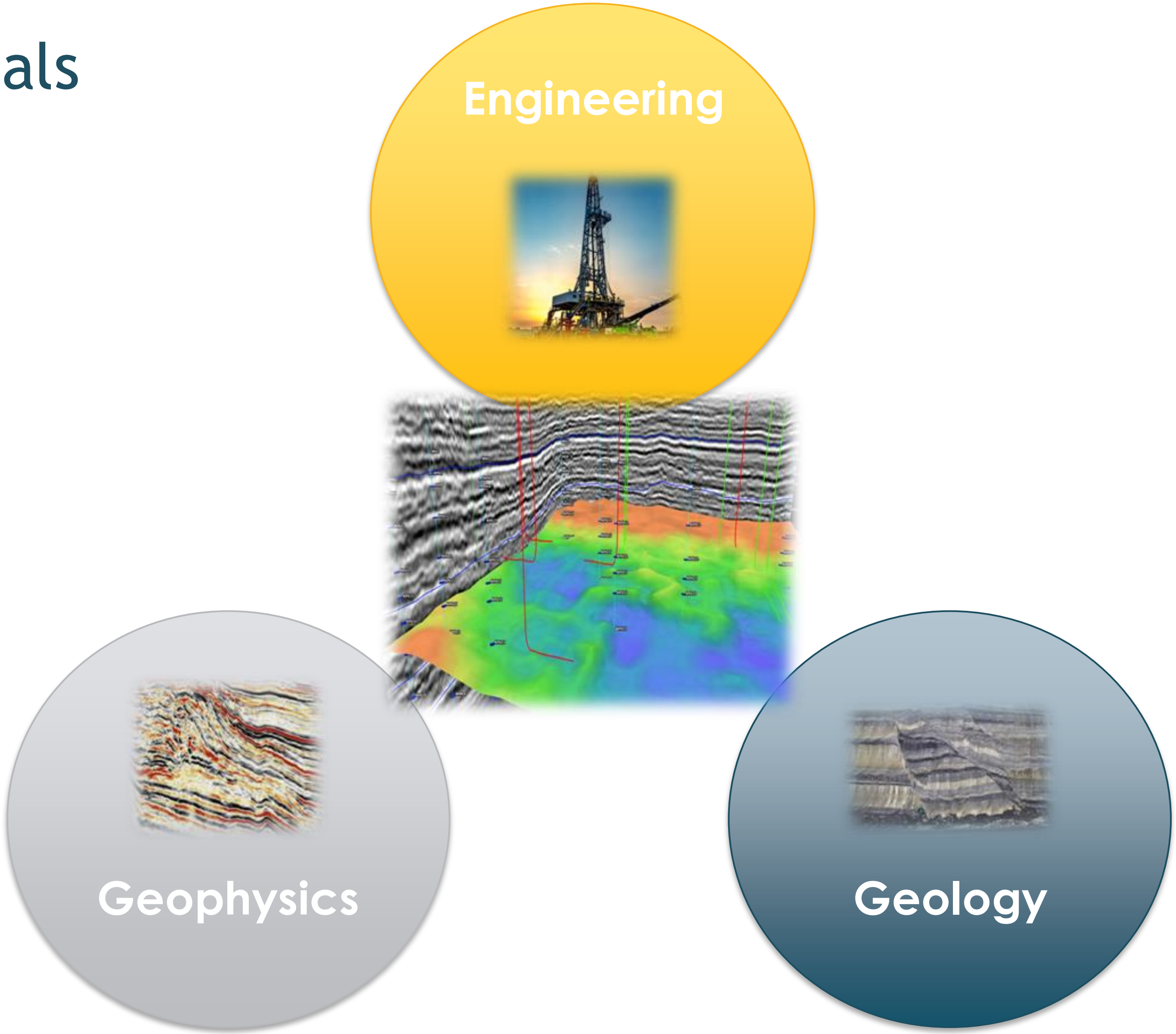
Starting model: (**a**) model, (**b**) stack, (**c**) gathers. 12 Hz FWI model: (**d**) model, (**e**) stack, (**f**) gathers. The 12 Hz FWI captures finer details related to geology.

Dongren Bai, Lin Zheng, and Wubing Deng, (2021), "Imaging the complex geology in the Central Basin Platform with land FWI," *SEG Technical Program Expanded Abstracts* : 592-596.

WE NEED EACH OTHER

Geoscience in Unconventionals

- Transition from **siloed** to **integrated** disciplines
- Reservoir quality defined by the ability to fracture rather than inherent porosity and permeability
- Planning, landing, drilling, and completing wells
  - Land in the right part of the desired formation
  - Avoid Drilling Hazards
  - Optimize Well-Spacing
  - Inform Completions



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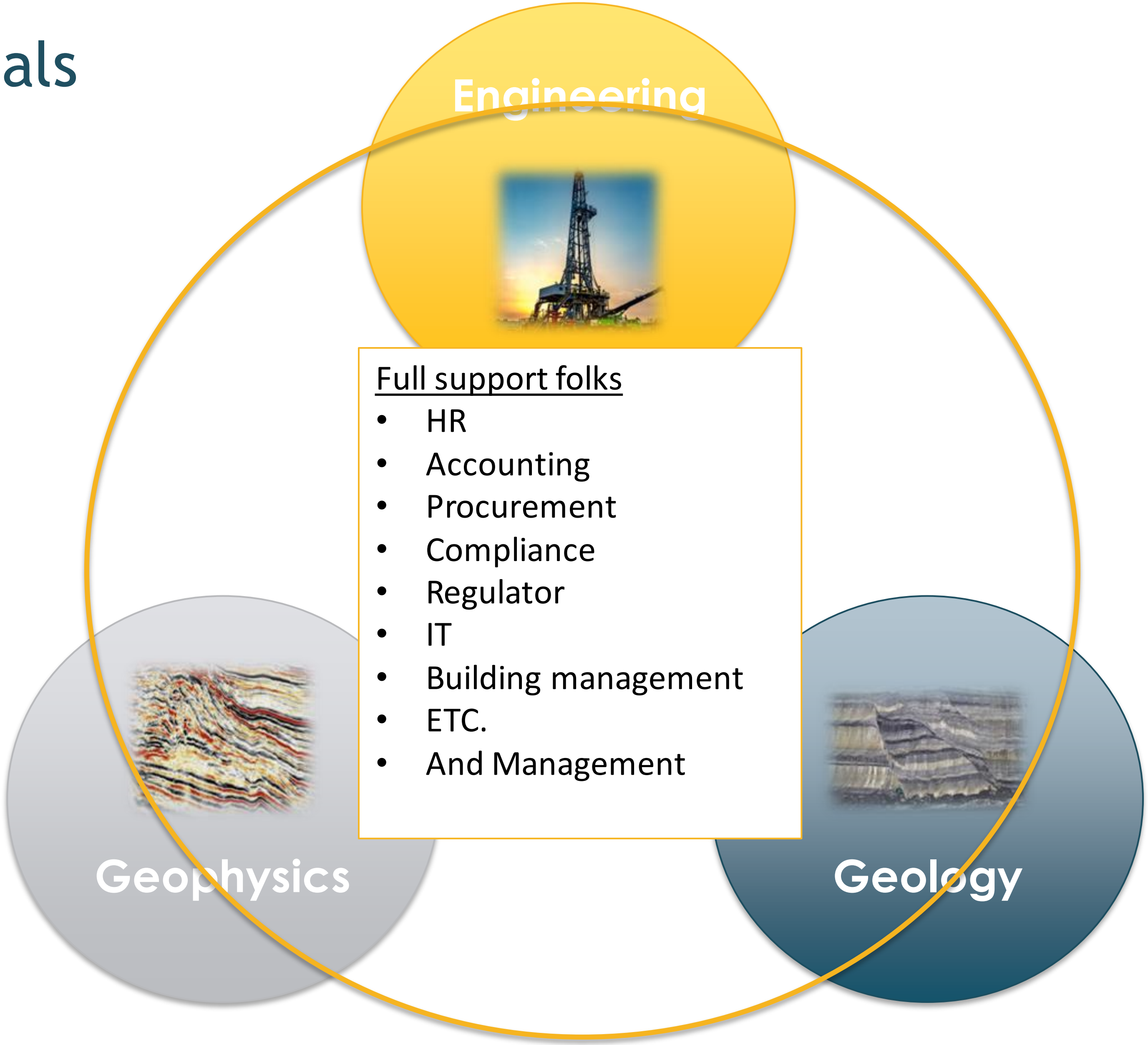

Full support folks
- HR
- Accounting
- Procurement
- Compliance
- Regulator
- IT
- Building management
- ETC.
- And Management

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3D Seismic Acquisition in the Permian Basin

Seismic Source: Vibroseis

Receiver: ZLand Node

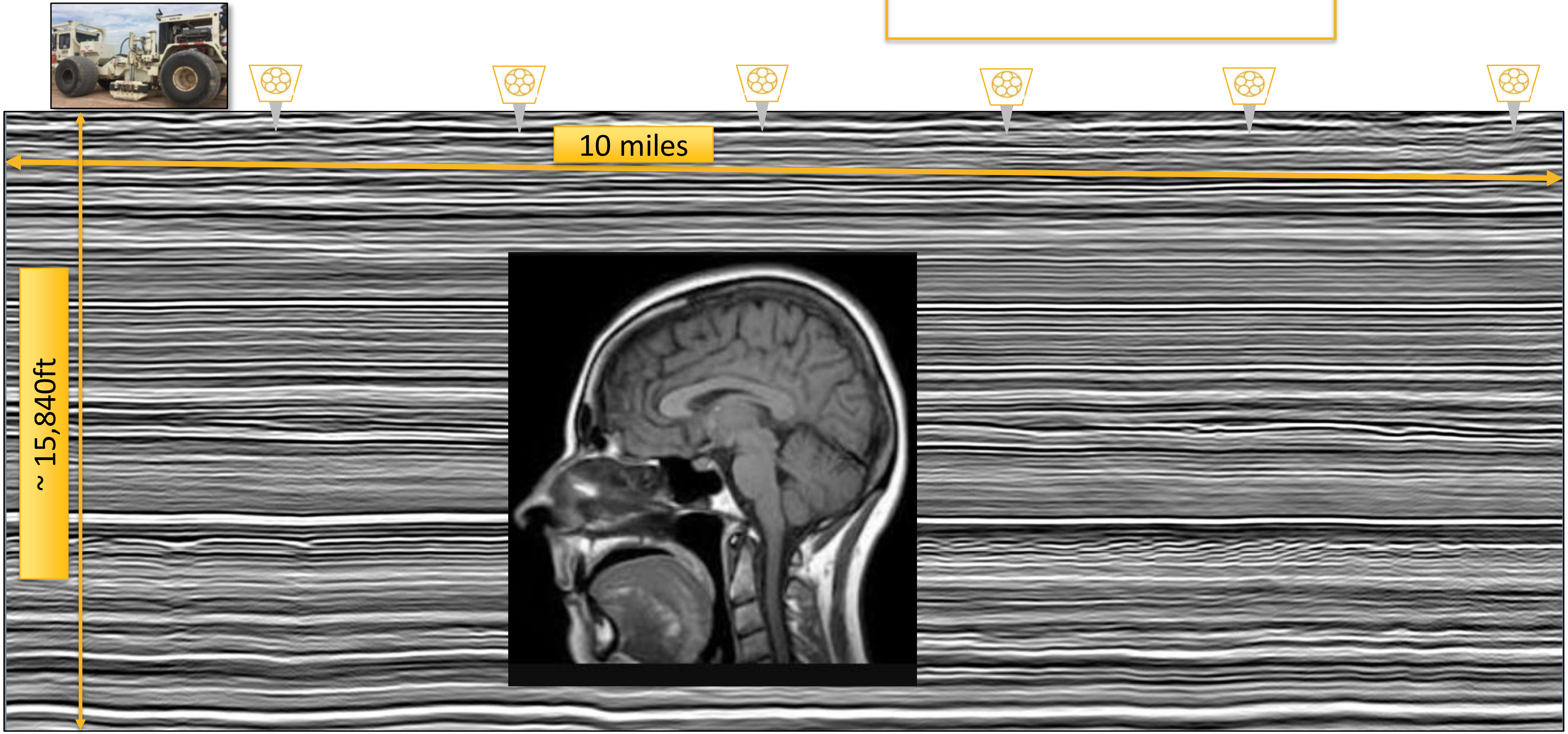
The Concept of Trace Density

- **Trace-Density** is the number of seismic traces collected in a given area (Physical location and sample of earth, 82.5ft X 82.5ft X 82.5ft) for 25,000ft from the surface.

- Trace-Density is apparent in different seismic acquisition domains:
  - **Offset,** or the distance from the source to the receiver
  - **Azimuth,** or the direction from the source to the receiver
  - **Fold**, or the number of times a subsurface location is sampled
  - **Bin Size**, the lateral extent of the subsurface sample

Slice of the earth; Fasken C-Ranch:

What is Offset?



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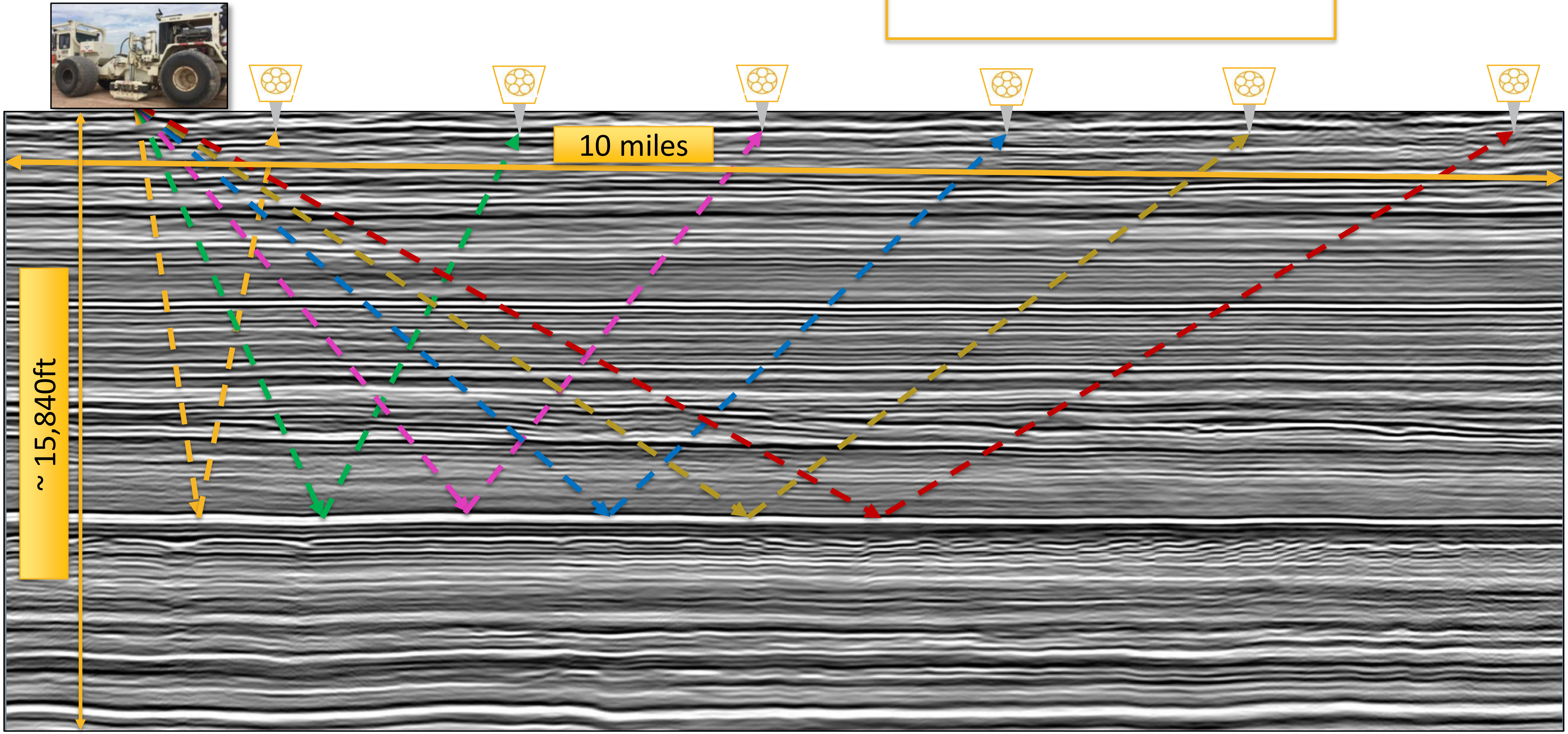
Slice of the earth; Fasken C-Ranch:

What is Offset?



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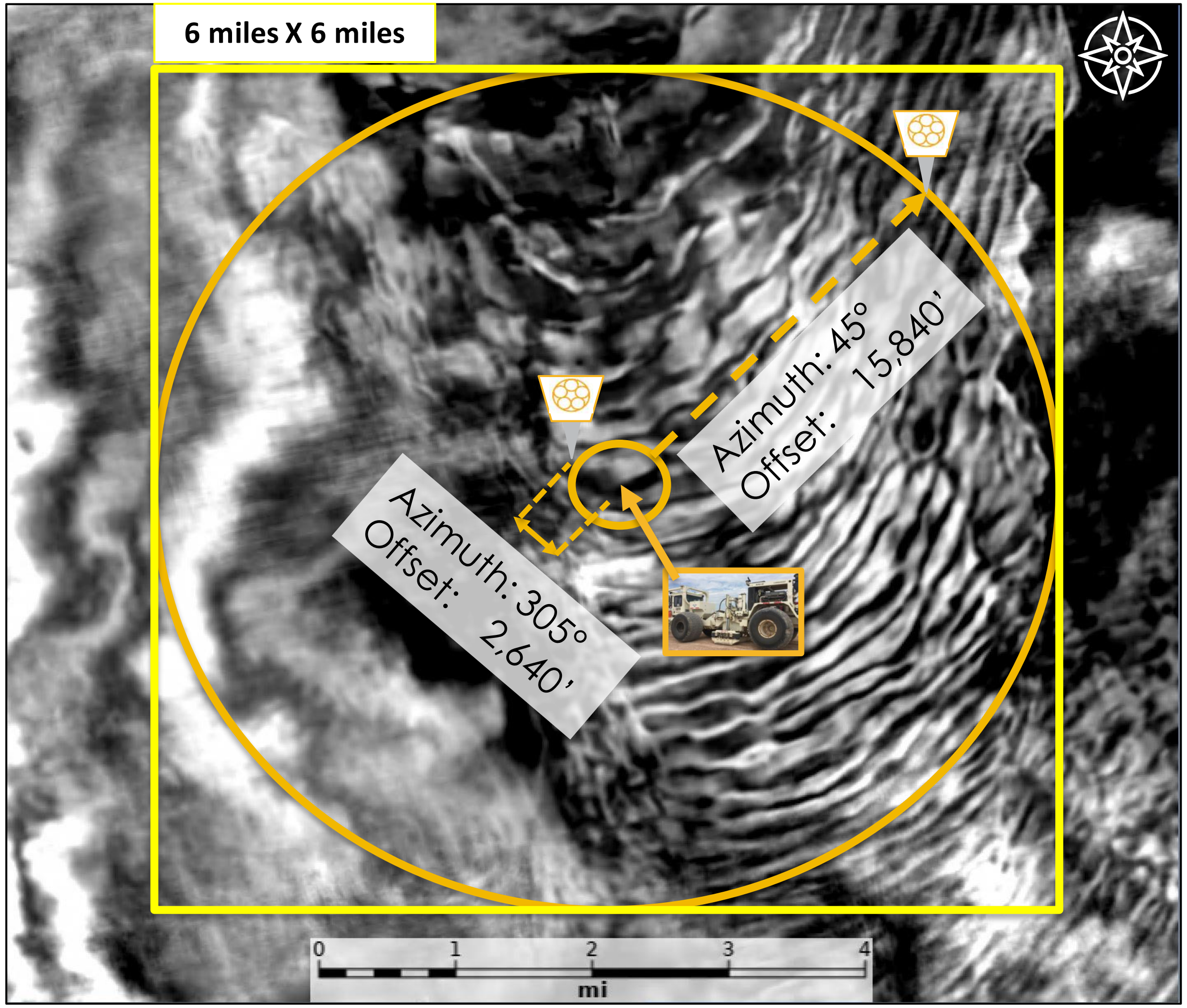
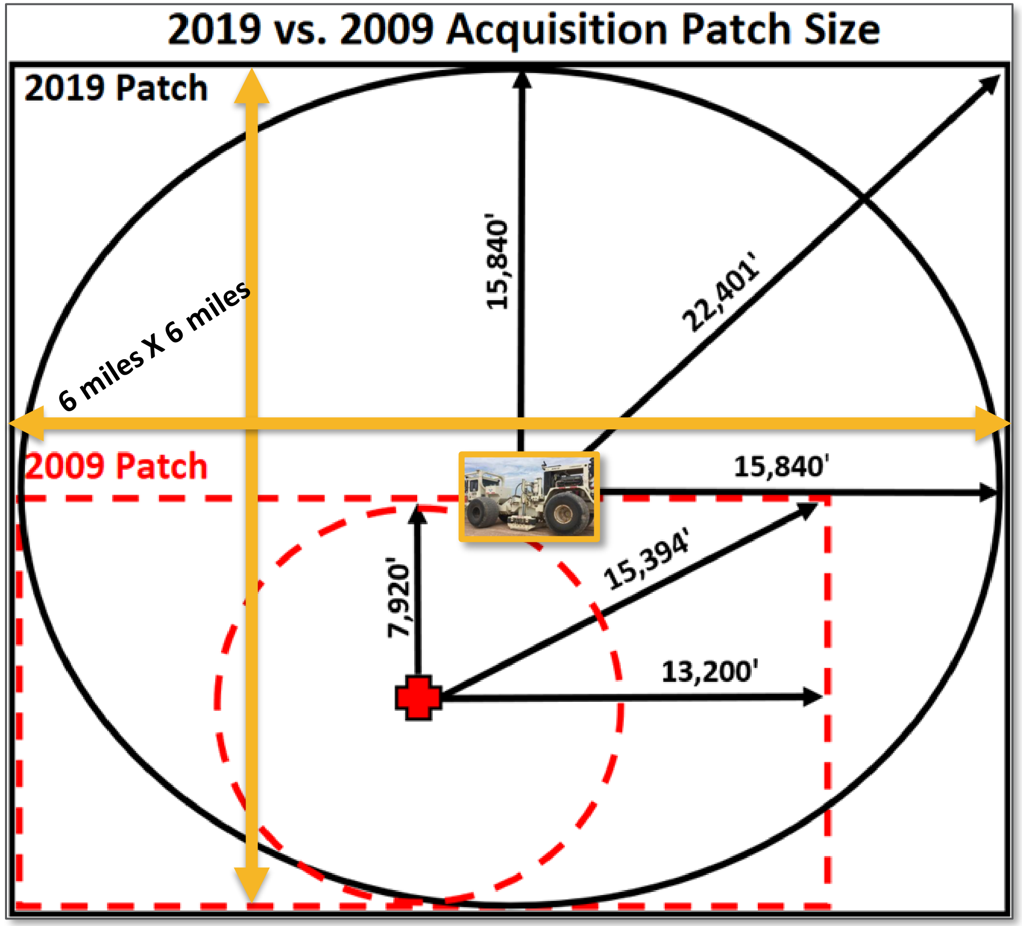
What is Azimuth?



36 square mile surface area "patch"
VS
15 square mile "patch" in red



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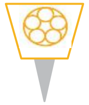
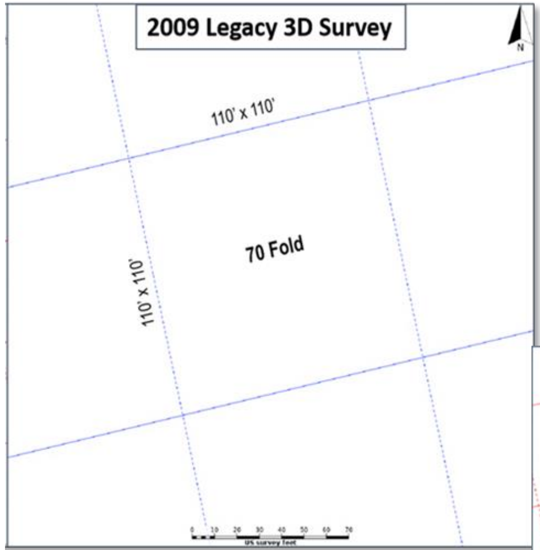
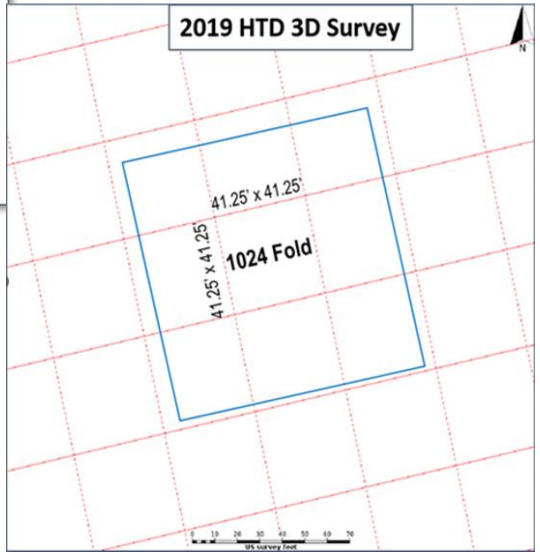
Bin Size and Fold

Red means sources

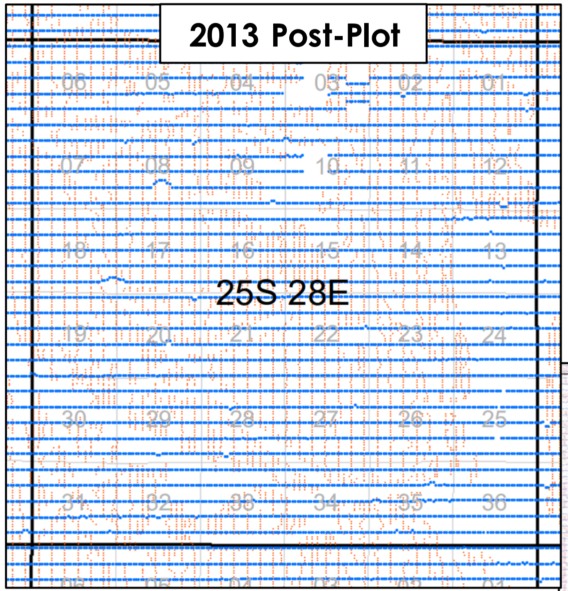


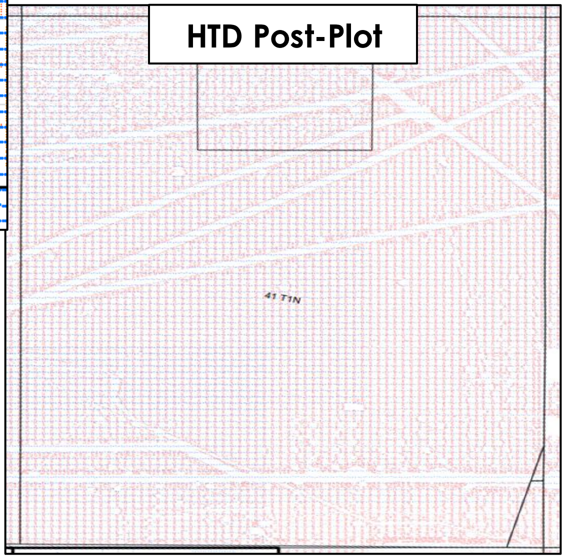
Blue means receivers





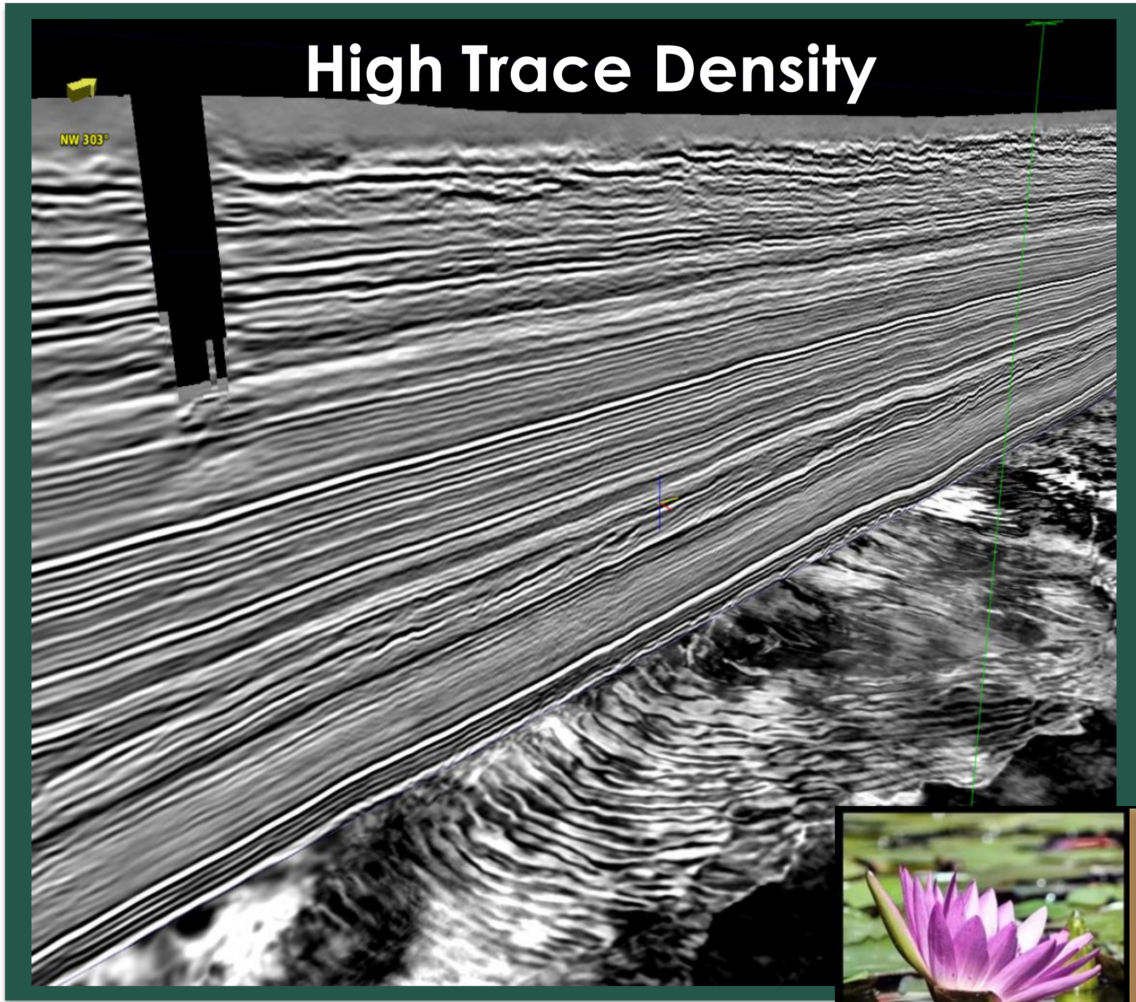
- Bin Size refers to the subdivision of a 3D seismic survey
- It's analogous to the number of pixels in a TV

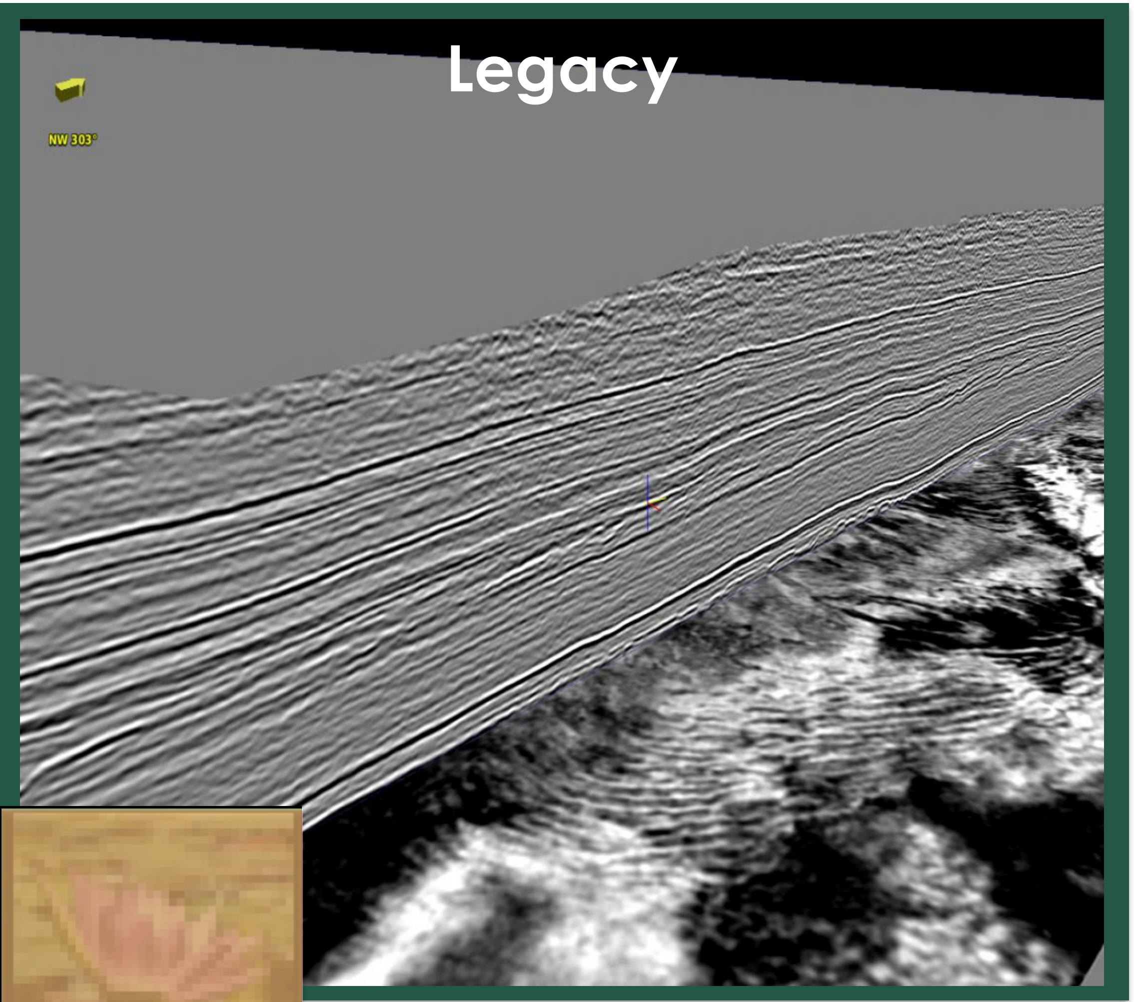


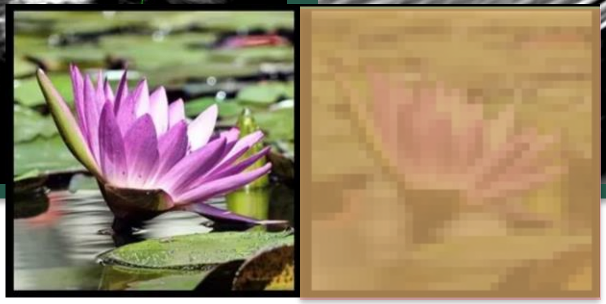


- Fold is the number of times that a subsurface sample is collected through various combinations of offset and azimuth
- High fold, **benefits the signal-to-noise ratio** of the seismic data

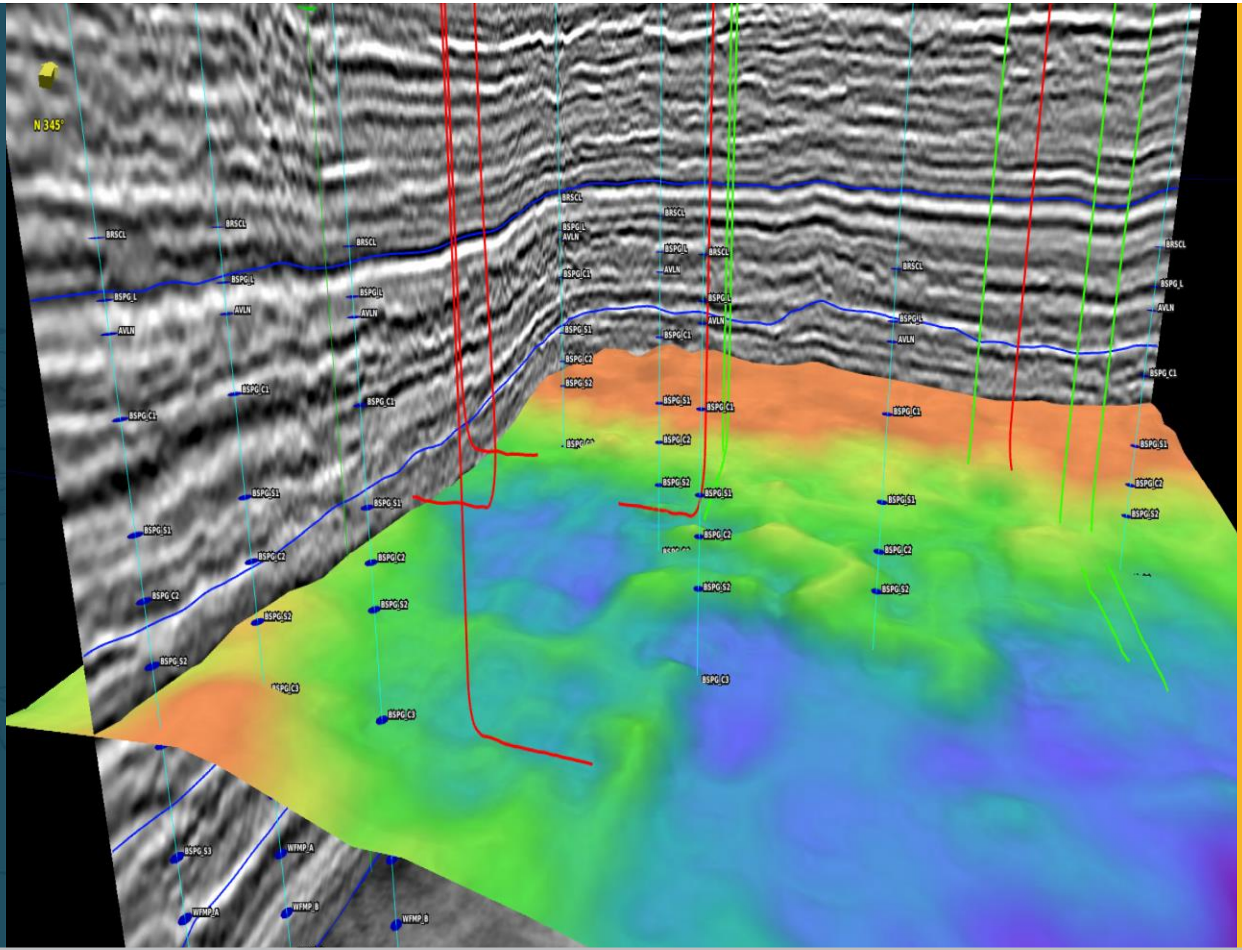
HTD vs. Legacy 3D Seismic Data







3D Seismic Resolution at Regional & Prospect-Level Scales



Andrew Lewis[1], Taylor Mackay[1]*
1. Fairfield Geotechnologies

Thursday November 10th, 2022

Outline

- 3D Seismic Resolution at the Regional Scale
  - Geologic Setting and 3D Seismic Coverage
  - Northern Delaware Basin Regional Merge
  - Arbitrary Lines, Regional Structure, & Depth Slice Movie

- 3D Seismic Resolution at the Prospect-Level Scale
  - Benefits of Data Integration
  - Production Lookback

- Improving 3D Seismic Resolution with High Trace Density (HTD) 3D Seismic

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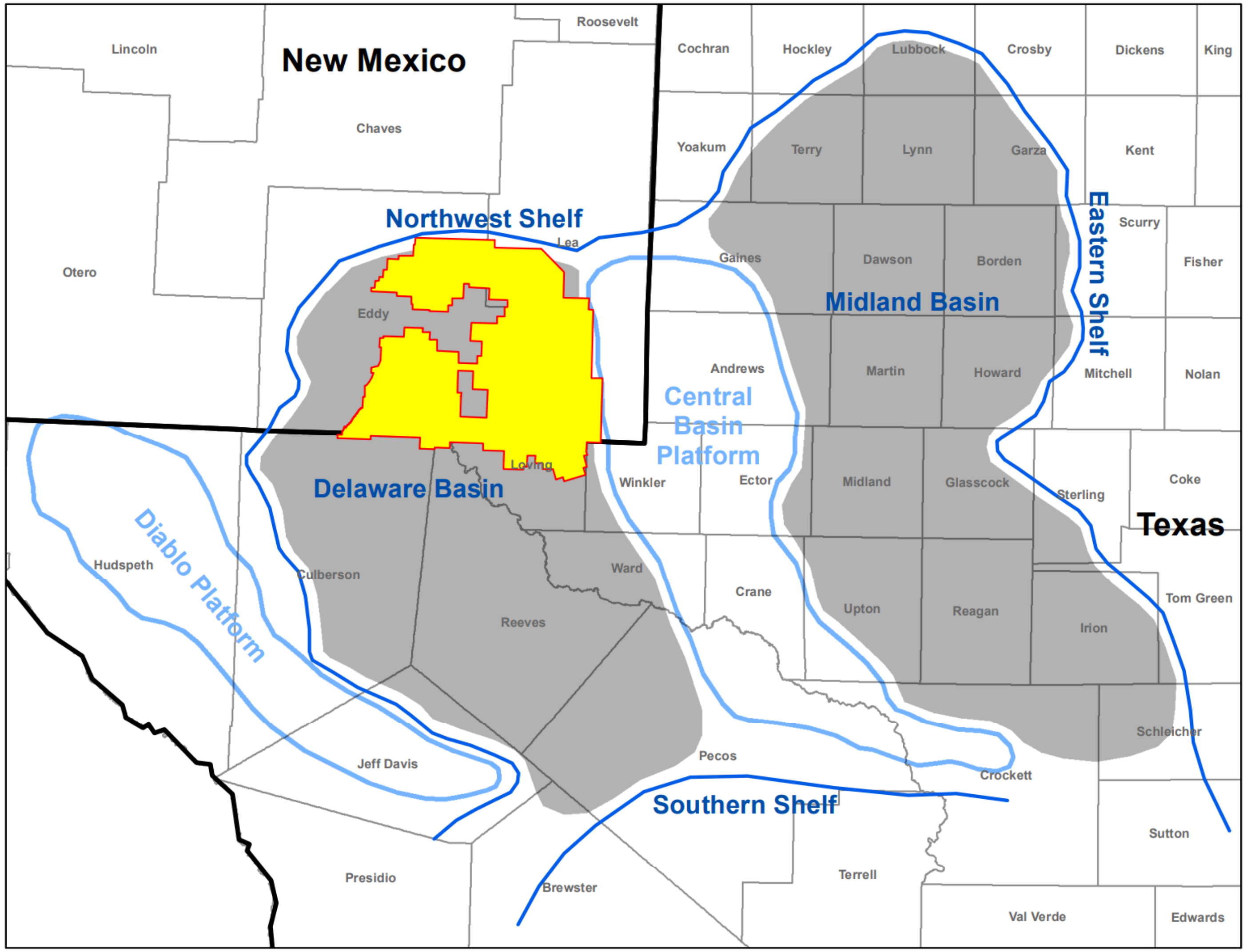
3D Seismic Resolution at the Regional Scale

Geologic Setting and 3D Seismic Coverage



System	Series	Delaware Basin Formations
PERMIAN	Ochoa	Rustler
		Salado
		Castille
	Guadalupe 271-260 MYA	
		Bell Canyon
		Cherry Canyon
		Brushy Canyon
	Leonard 280-271 MYA	Avalon
		First Bone Spring Sand
		Second Bone Spring Carbonate
		Second Bone Spring Sand
		Third Bone Spring Carbonate
		Third Bone Spring Sand
	Wolfcamp 299-280 MYA	Wolfcamp A
		Wolfcamp B
		Wolfcamp C
		Wolfcamp D
PENNSYLVANIAN	Virgil	Cisco
	Missouri	Canyon
	Des Moines	Strawn
	Atoka	Atoka
MISSISSIPPIAN	Chester	Barnett
		Woodford
DEVONIAN		Devonian
SILURIAN		Silurian
		Fusselman
ORDOVICIAN	Upper	Sylvan
		Montoya
	Middle	Simpson
	Lower	Ellenburger
CAMBRIAN	Upper	Cambrian

Adapted from Yang and Dorobek, 1995

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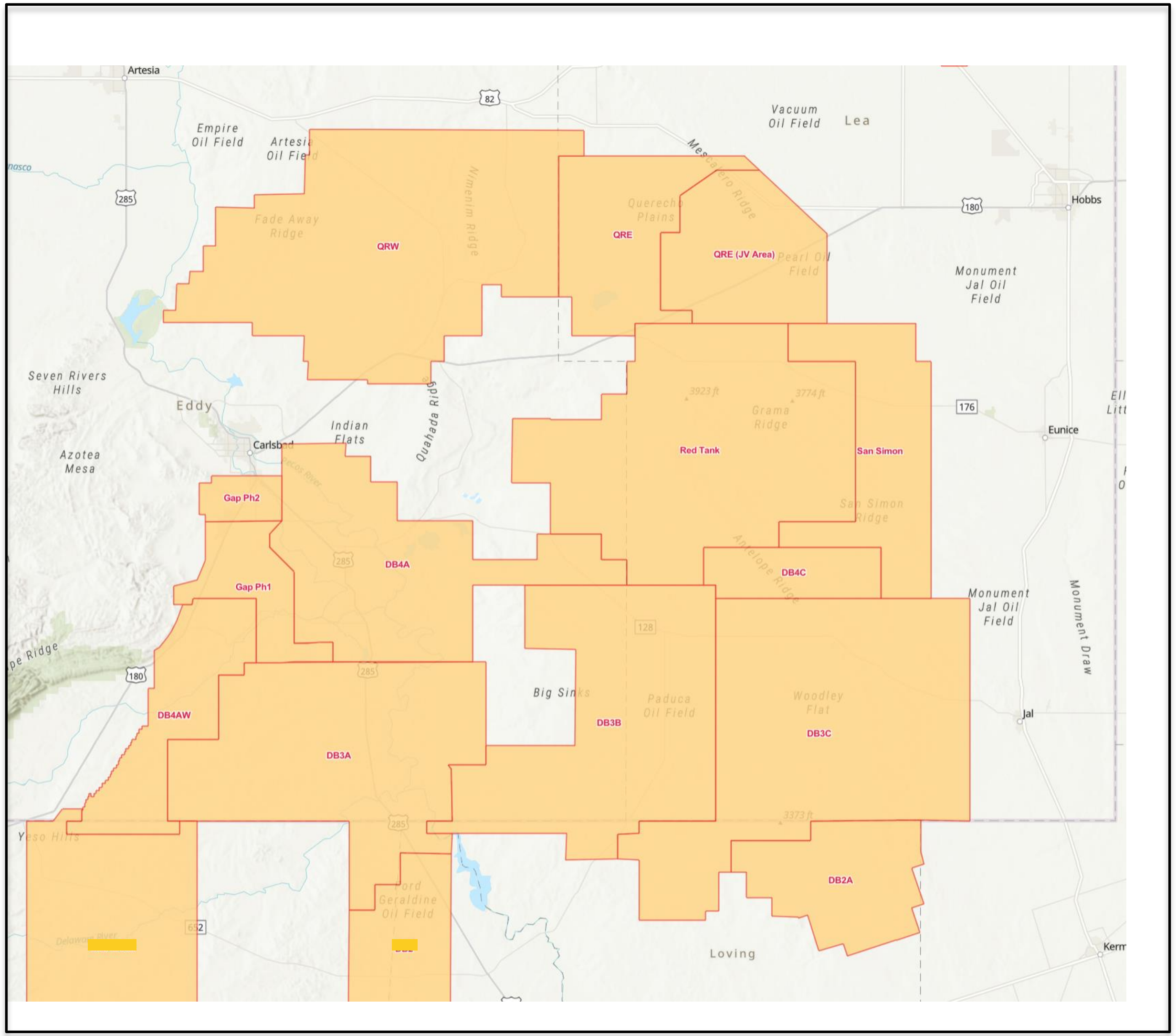
Northern Delaware Basin Regional Merge

- Regional Merge of Twelve 3D Seismic Surveys (PSDM)
  - Square Miles: 2,834
  - Vintages: 2013 – 2019
  - Nominal Fold: 324 – 600
  - Stacked Traces: 11,608,064
  - **Total Traces: 4,788,703,232**
- Processing Complete in Oct. 2021



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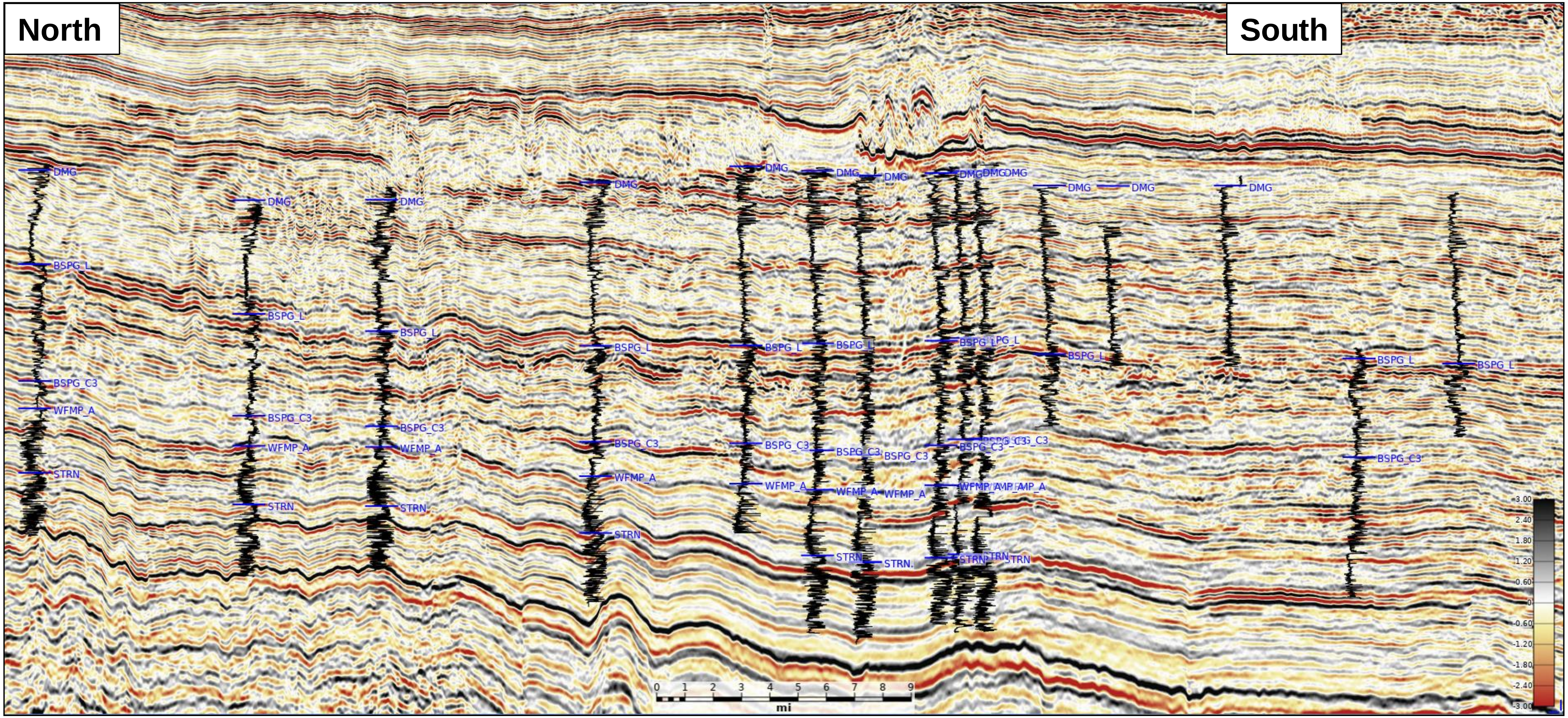
PSDM Stack with Sonic: N-S Arbline (65 miles)



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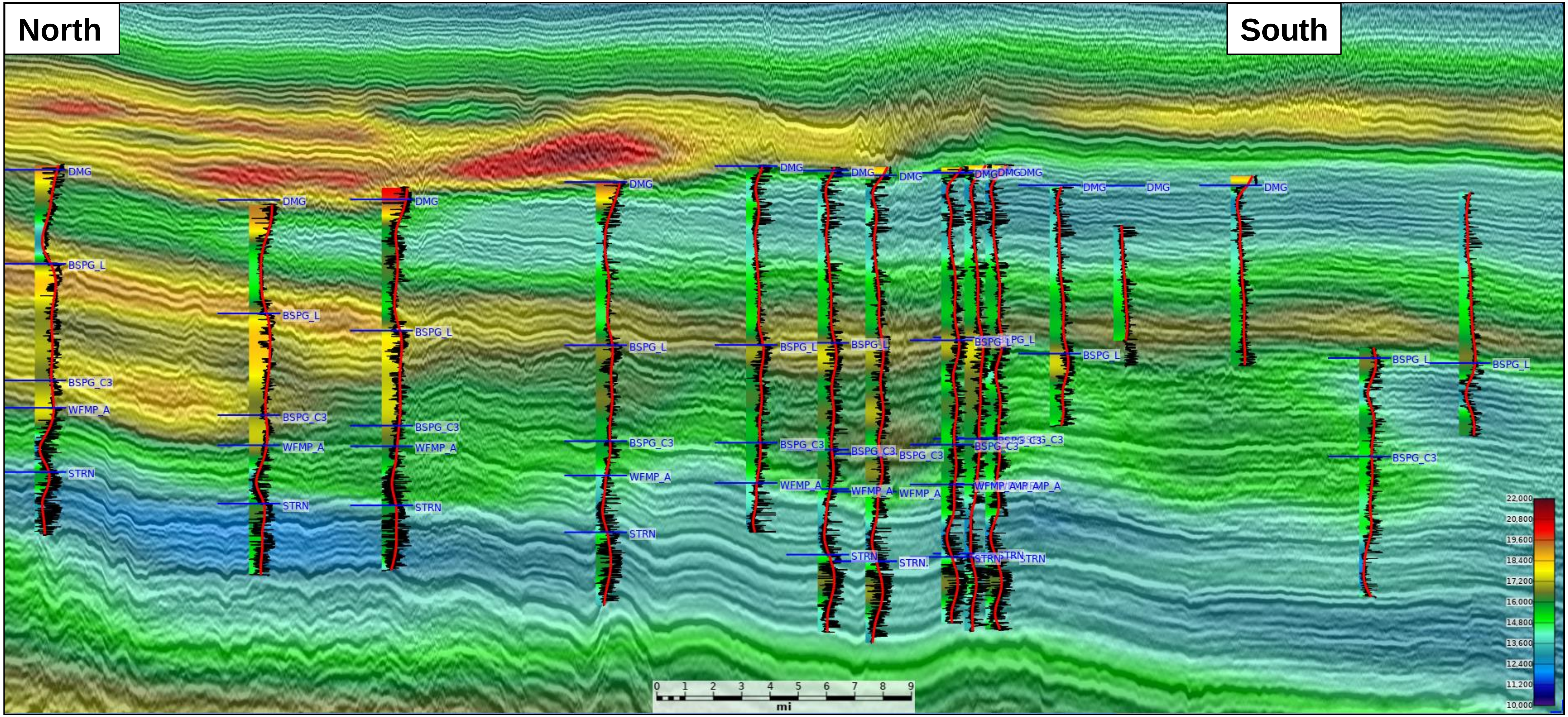
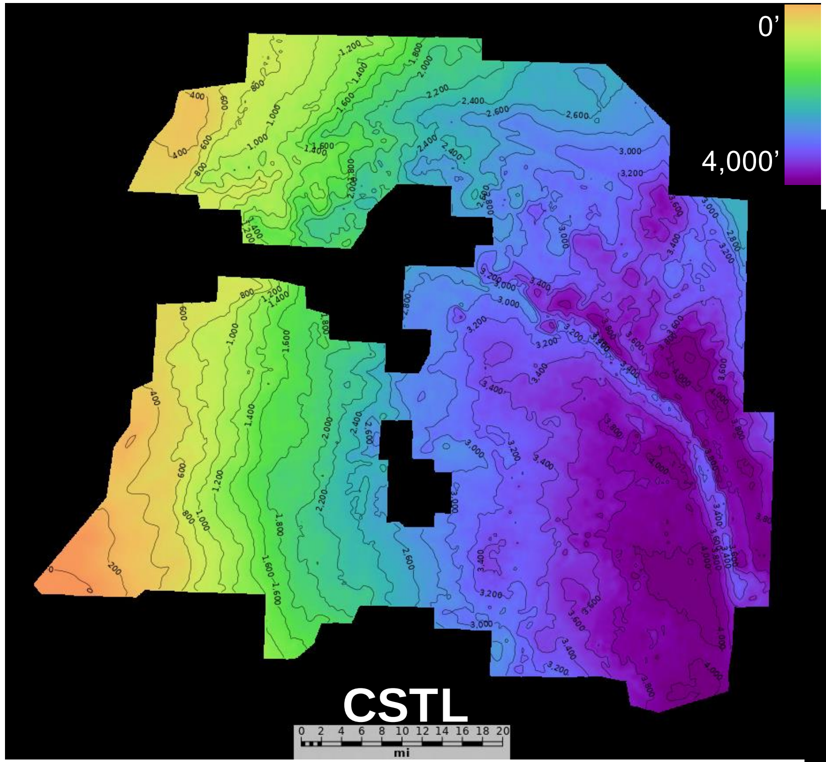
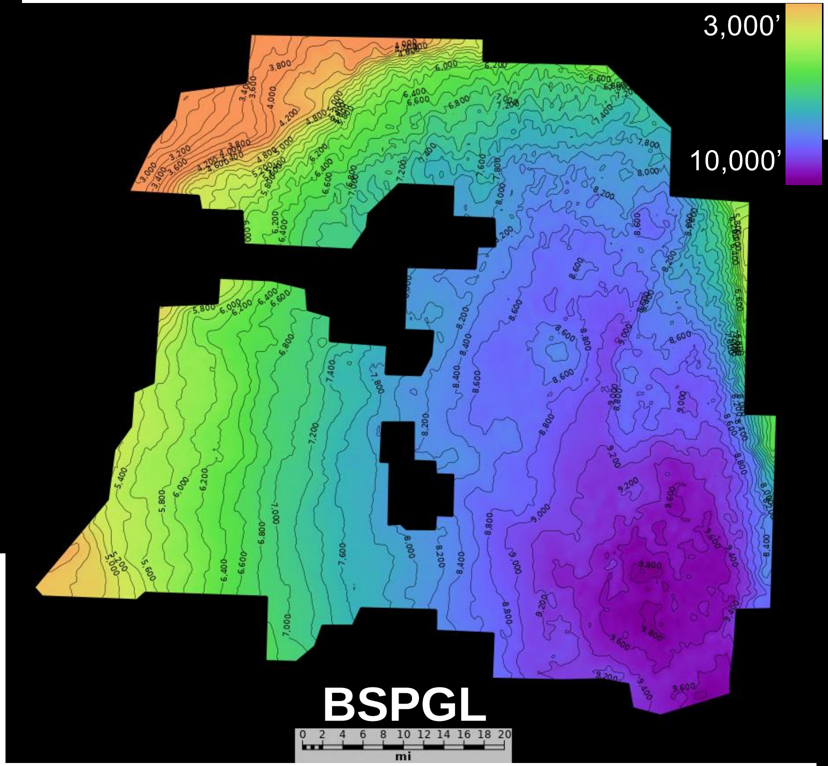
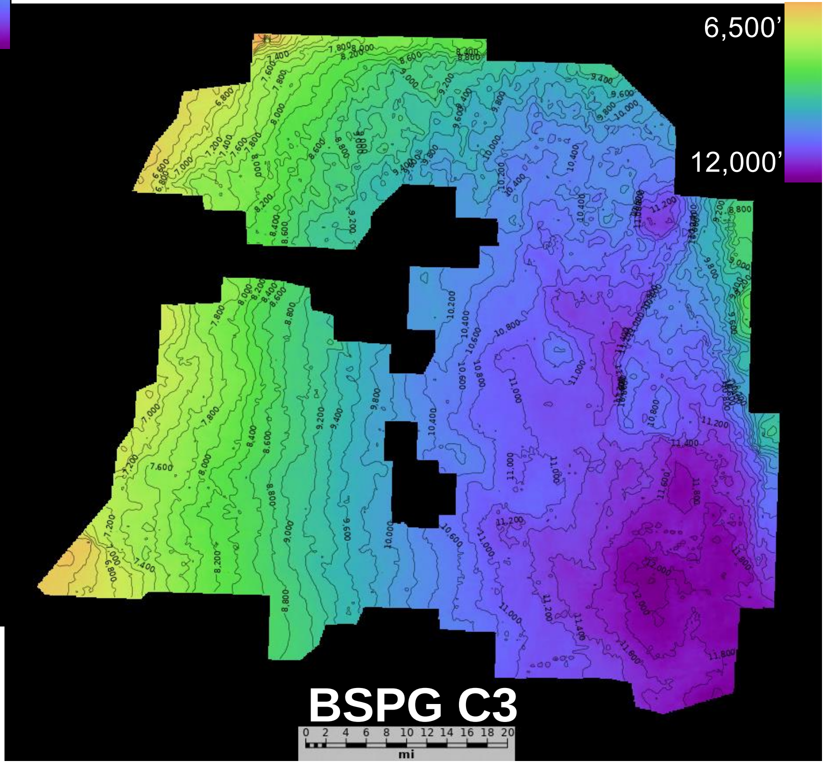
PSDM Velocities: Quail Ridge N-S Arbline (65 miles)



Regional Structure Maps







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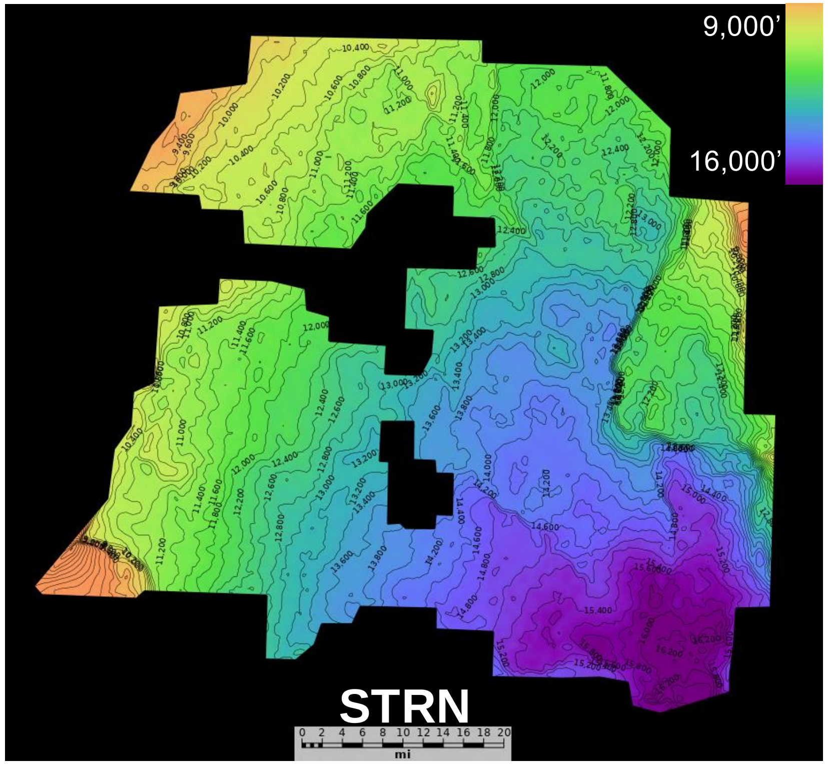
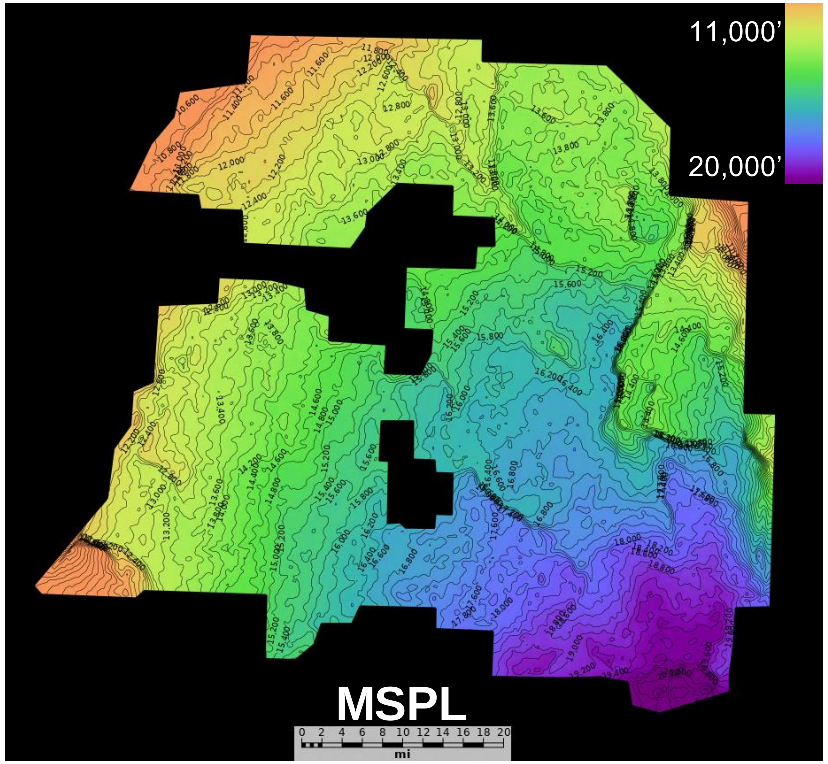
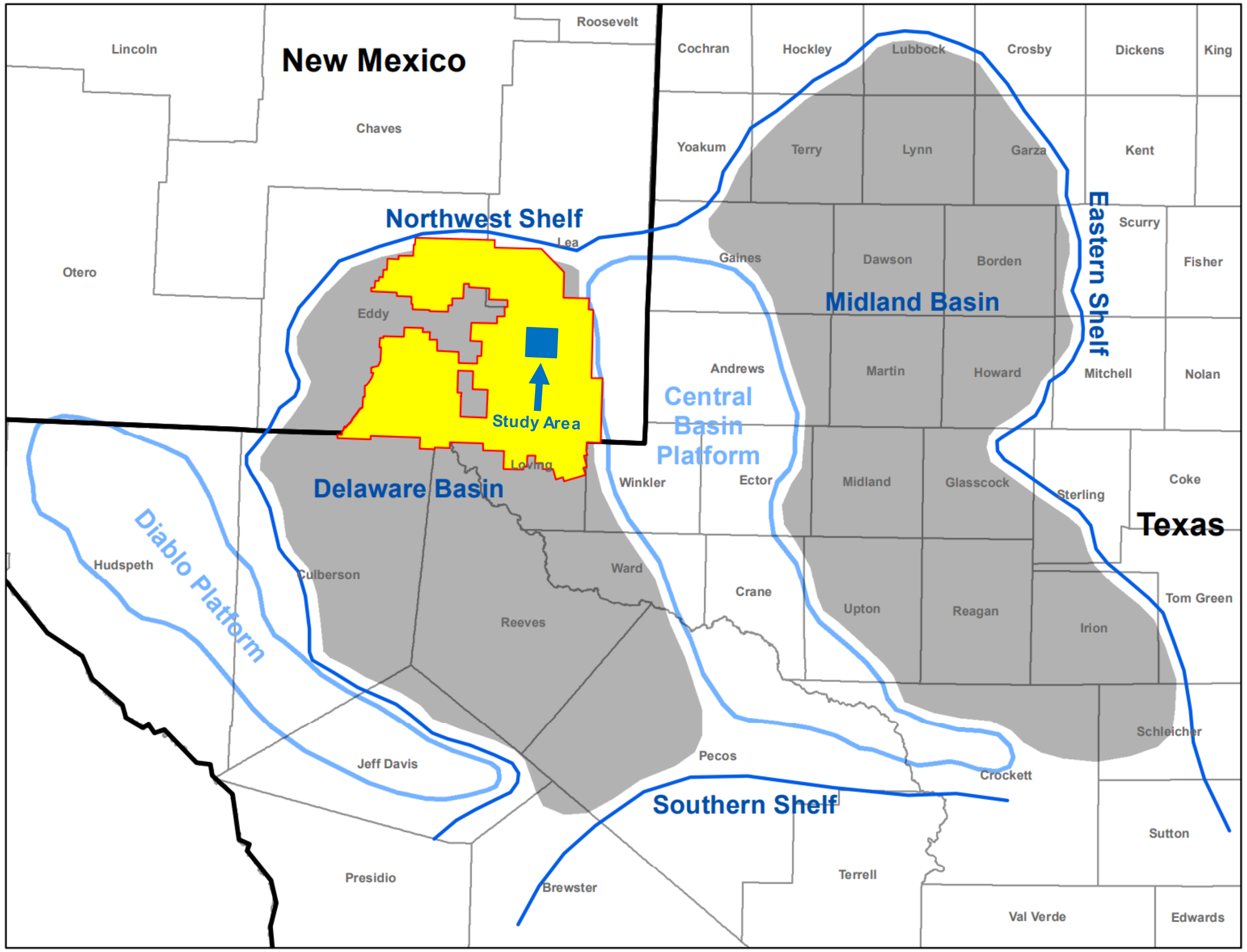




3D Seismic Resolution at the Prospect-Level Scale

2nd Bone Spring Sand at the Prospect Level Scale



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Modified from Yang and Dorobek, 1995

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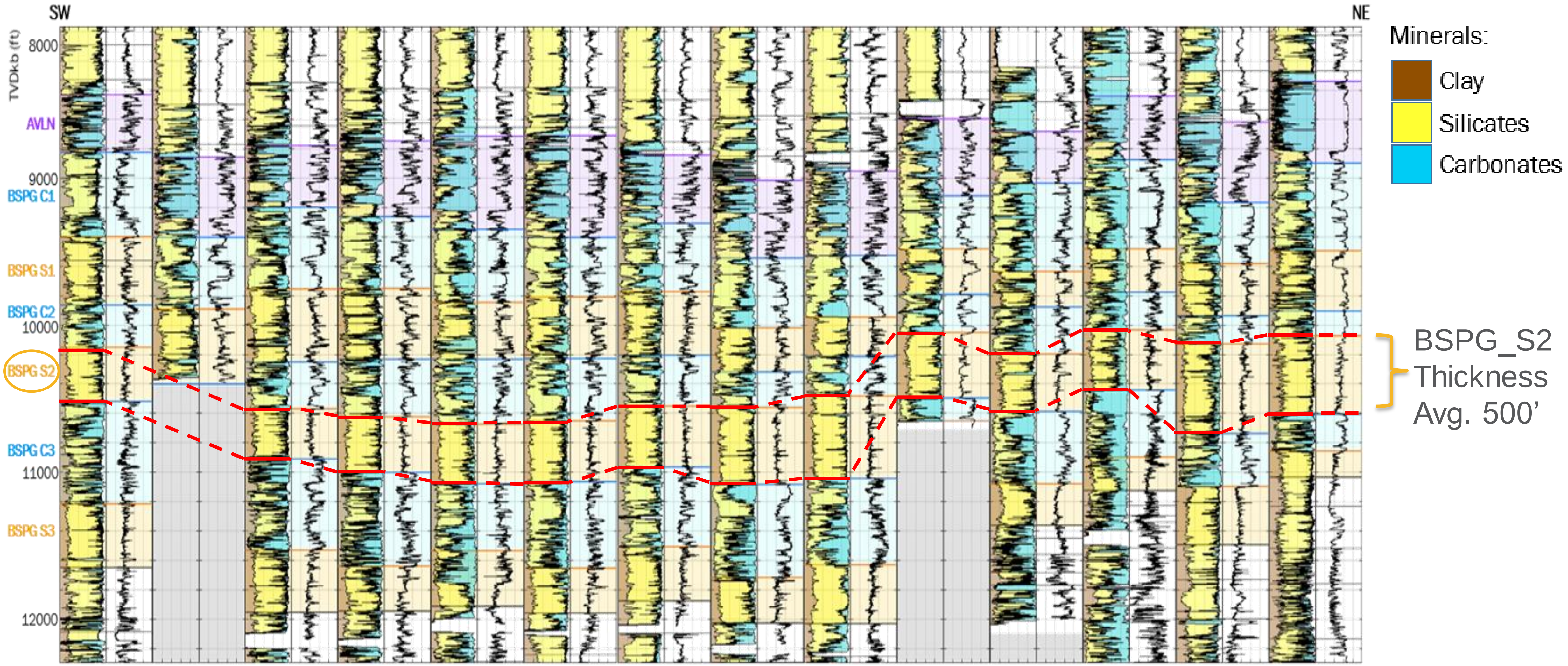
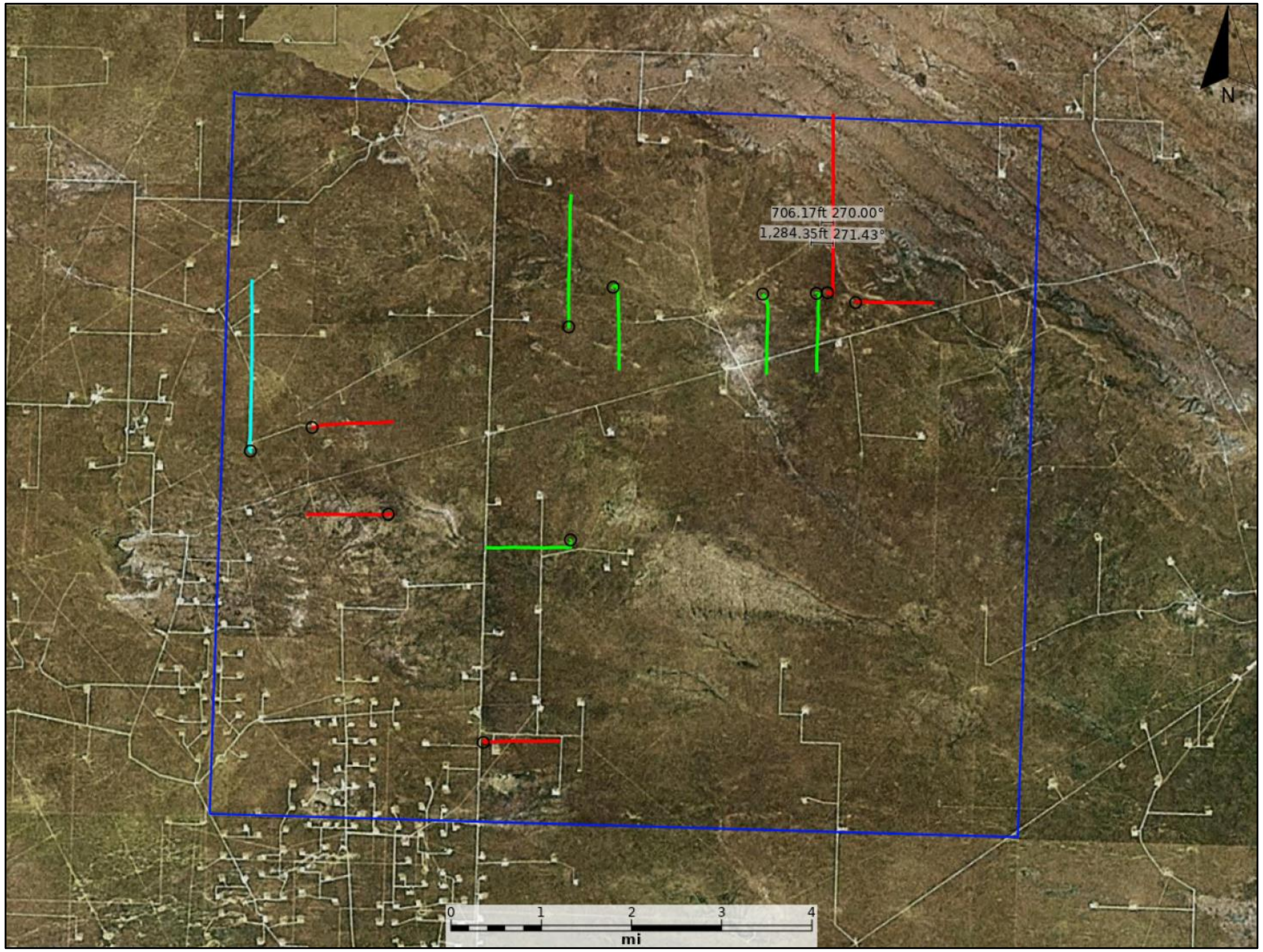
Bone Spring Cross Section



2nd Bone Spring Sand Well Performance Evaluation

- ~ 70 Sq. Mi. of 3D Seismic
- 12 wells with sonic for depth conversion
- Wells sorted by First 12 BOE per ft
- Top 5 wells in **GREEN**
  - 4 N-S Wells
  - 1 E-W Well
- Bottom 5 wells in **RED**
  - 4 E-W Wells
  - 1 N-S Well
- **Blue** Well has MWD



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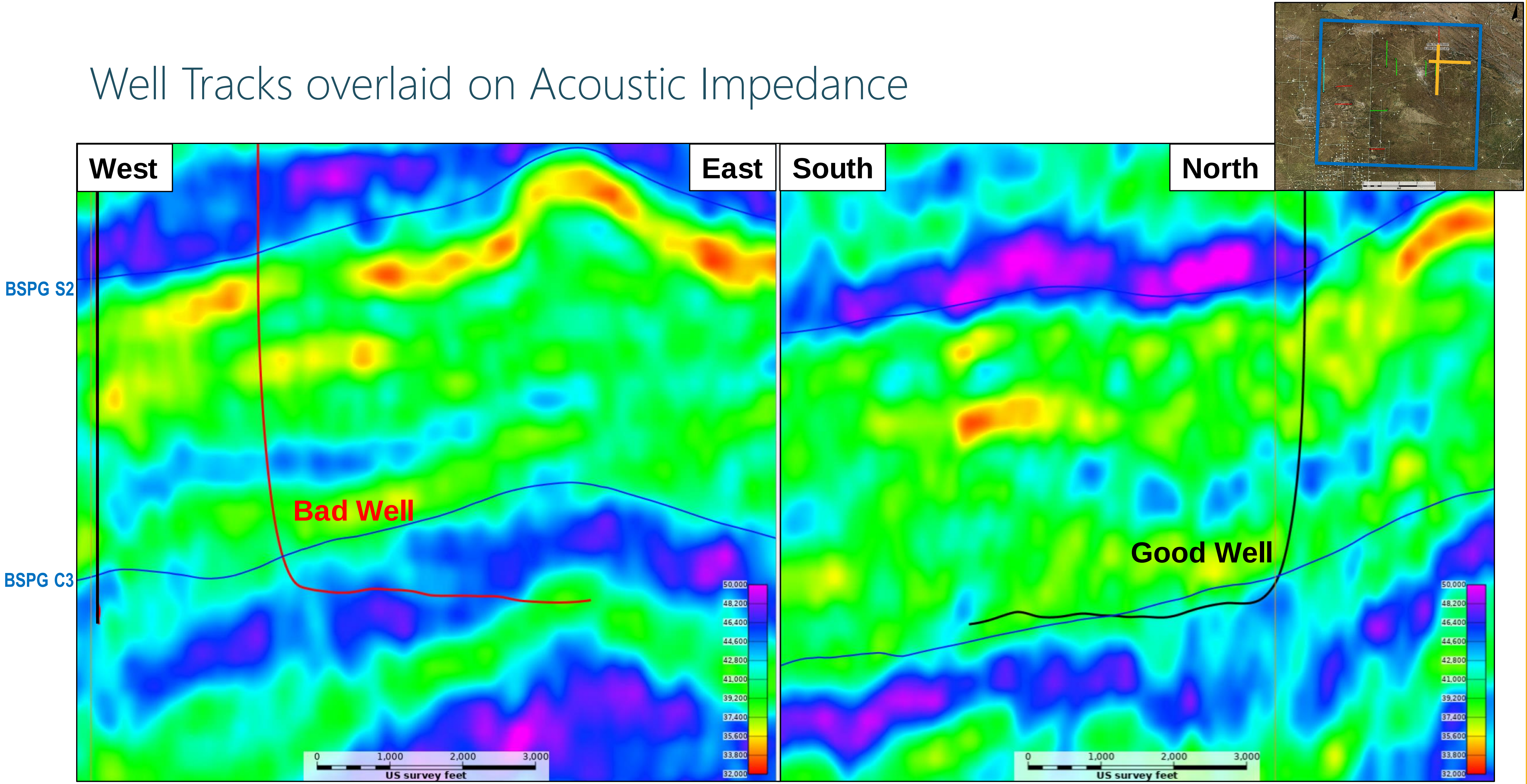
Well Tracks overlaid on Acoustic Impedance



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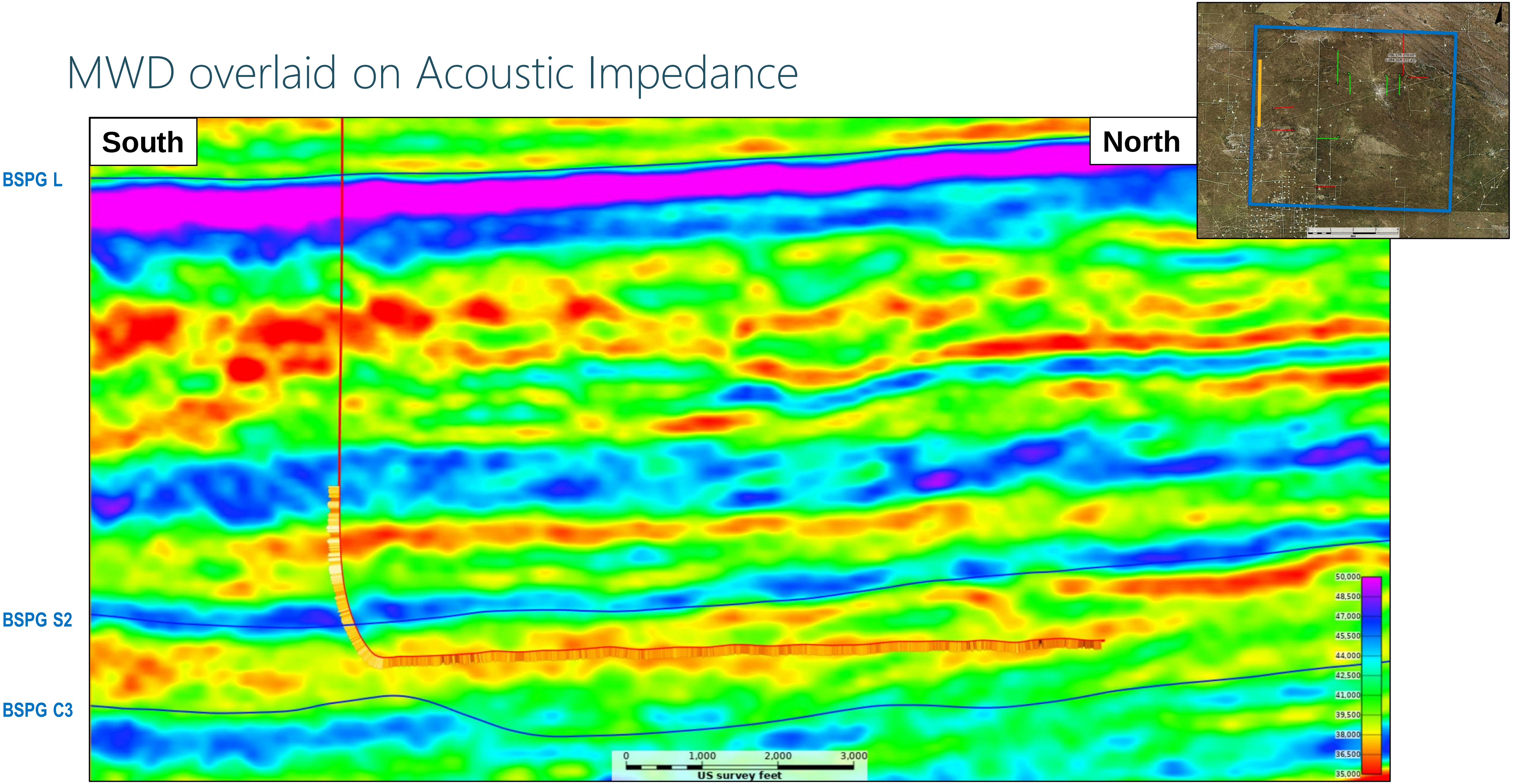
MWD overlaid on Acoustic Impedance



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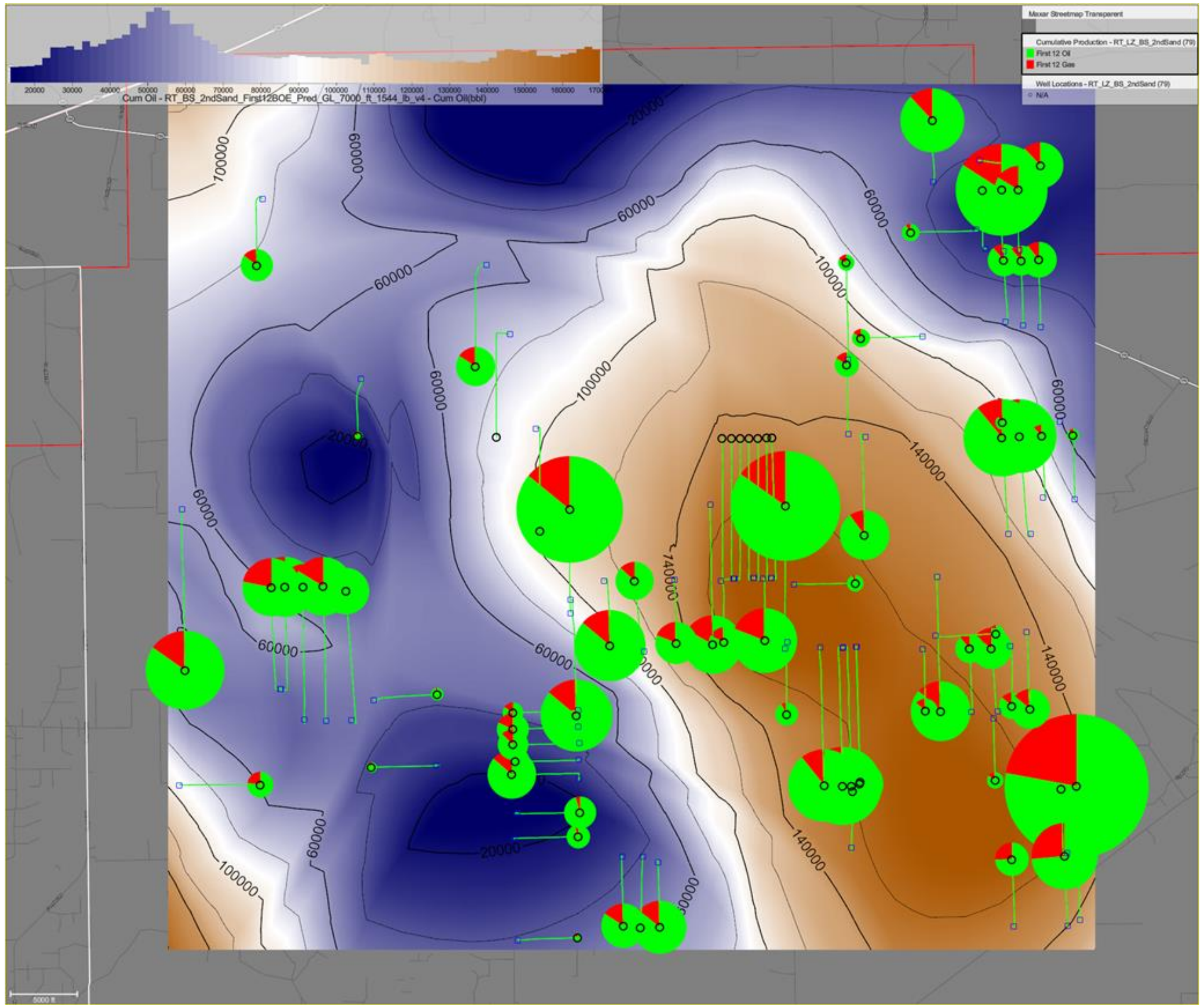
Predicting First 12 BOE with Multi-Variate Statistics

- Bubble Diagram
  - Oil is **GREEN**
  - Gas is **RED**

- Notice increased detail in lateral resolution

- Uncertainty decreases as more subsurface data is integrated into the predictive model for 1st 12 BOE

	Engineering Model	Engineering + Geology Model	Engineering + Geology + Geophysics Model
n	54	51	42
R-Squared	.798	.847	.894
Mean Absolute Error (bbls)	40,000	31,800	22,900
Average Absolute Error (bbls) (Leave-One-Out)	52,700	44,000	42,700
MVStats Nonlinear Regression Variables (ordered by significance)	Proppant / perforated foot Lateral length Average depth of lateral Azimuth of lateral	Proppant / perforated foot Average gamma ray Lateral length Phi-Diff (clay indicator) Deep Resistivity (log10)	Proppant / perforated foot Lateral length Deep Resistivity (log10) Phi-Diff (clay indicator) Average gamma ray Acoustic Impedance K Min-Max (curvature)



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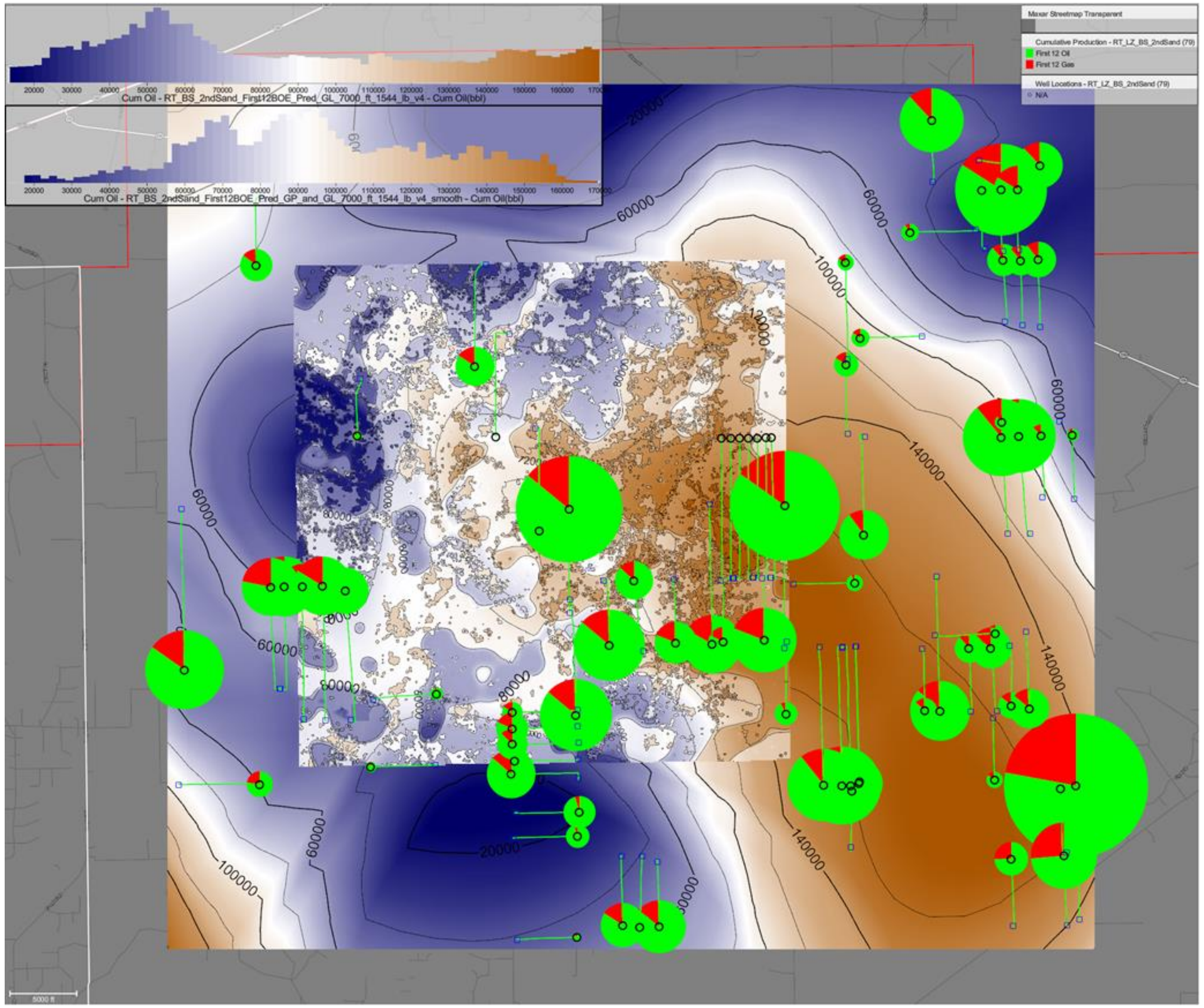
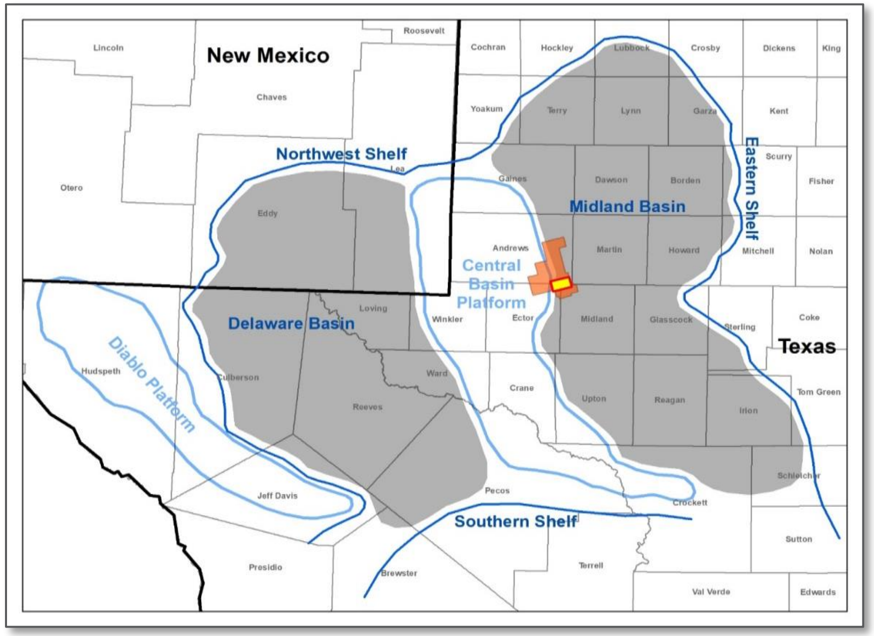


Improving 3D Seismic Resolution via HTD 3D

Collecting the Missing Data with High Trace Density 3D Seismic

- Finer Sampling of near and far offsets
- Finer lateral sampling
- Increased fold
- Broader frequency vibroseis sweep
- Fuller azimuthal sampling



Vintage:	2019 Acquisition Parameters	2013 Acquisition Parameters
CDP Bin Dimensions:	41.25' x 41.25'	82.5' x 82.5'
Nominal Fold:	1024	330
Record Length:	6 seconds	5 seconds
Source Interval:	82.5' (dual source lines)	165'
Sources per square mile	1370	205
Source Line Spacing:	495'	825'
Number vibs	2	4
Sweeps per Vibrator Point:	1	3
Sweep Bandwidth:	2-92 Hz	4-76 Hz
Sweep Length:	24 seconds	16 seconds
Linear or Nonlinear Sweep:	Nonlinear | Low Dwell	Linear
Receiver Interval:	165'	165'
Receiver Line Spacing:	495'	990'
Receivers per square mile	342	171
Recording Geometry (lines x channels):	64 X 192 = 12,288	30 X 220 = 6,600
Recording Swath Dimensions:	15,840' X 15,840'	28,710' X 36,135'
Off Diagonal (maximum offset)	22,401'	23,076'
Trace Density per square mile	16,777,216	1,351,680

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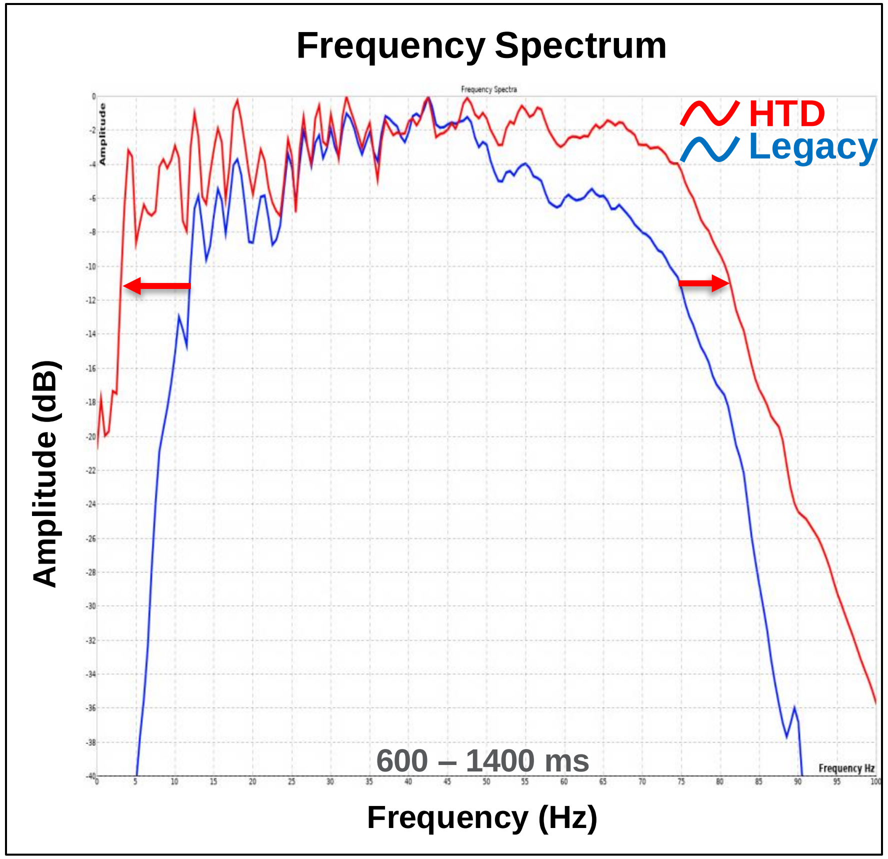
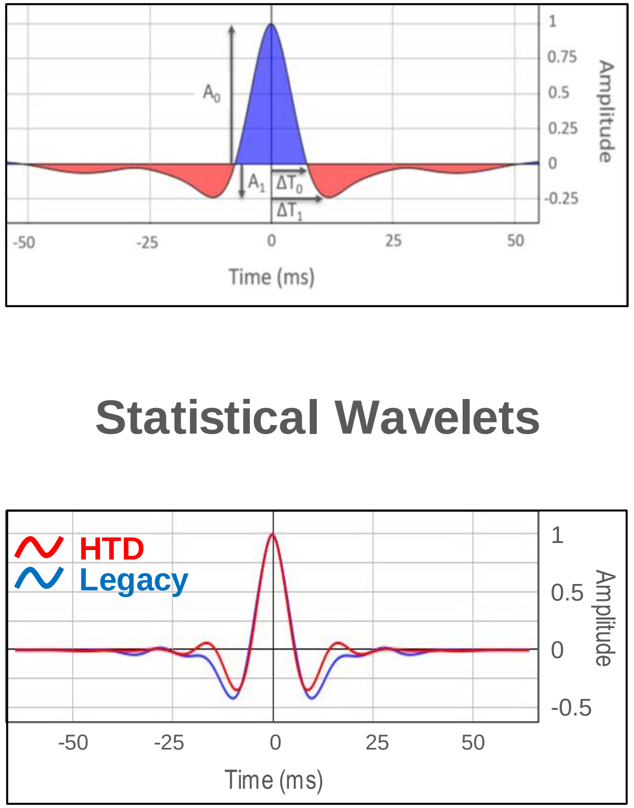
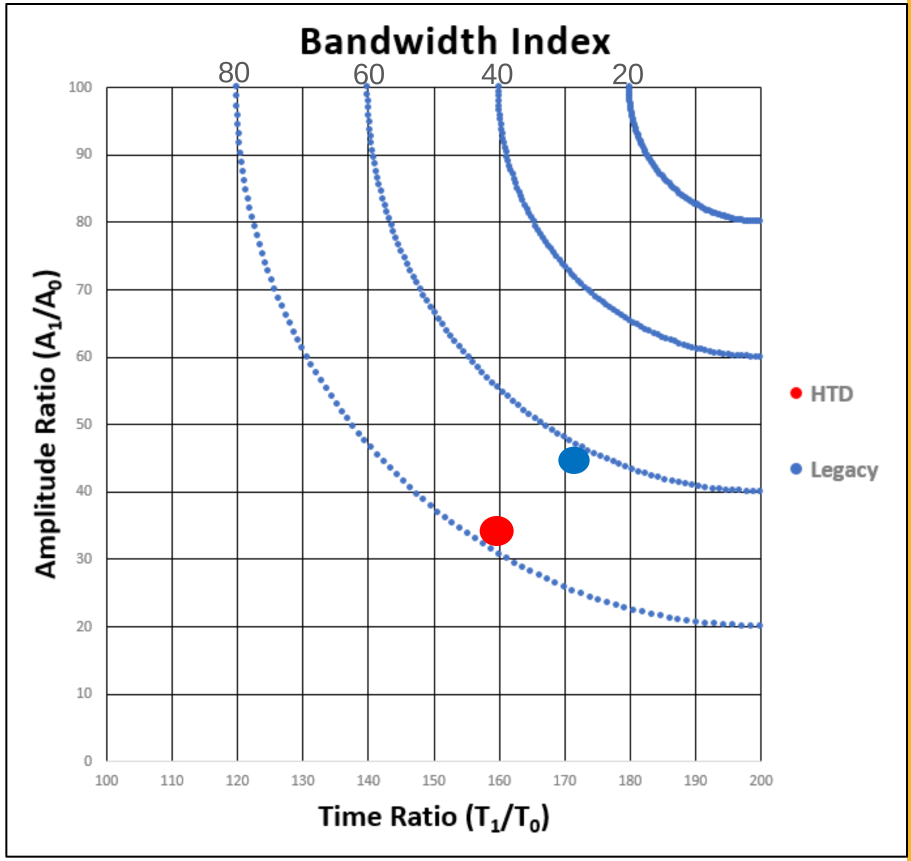
Vertical Resolution







Araman et al., 2012

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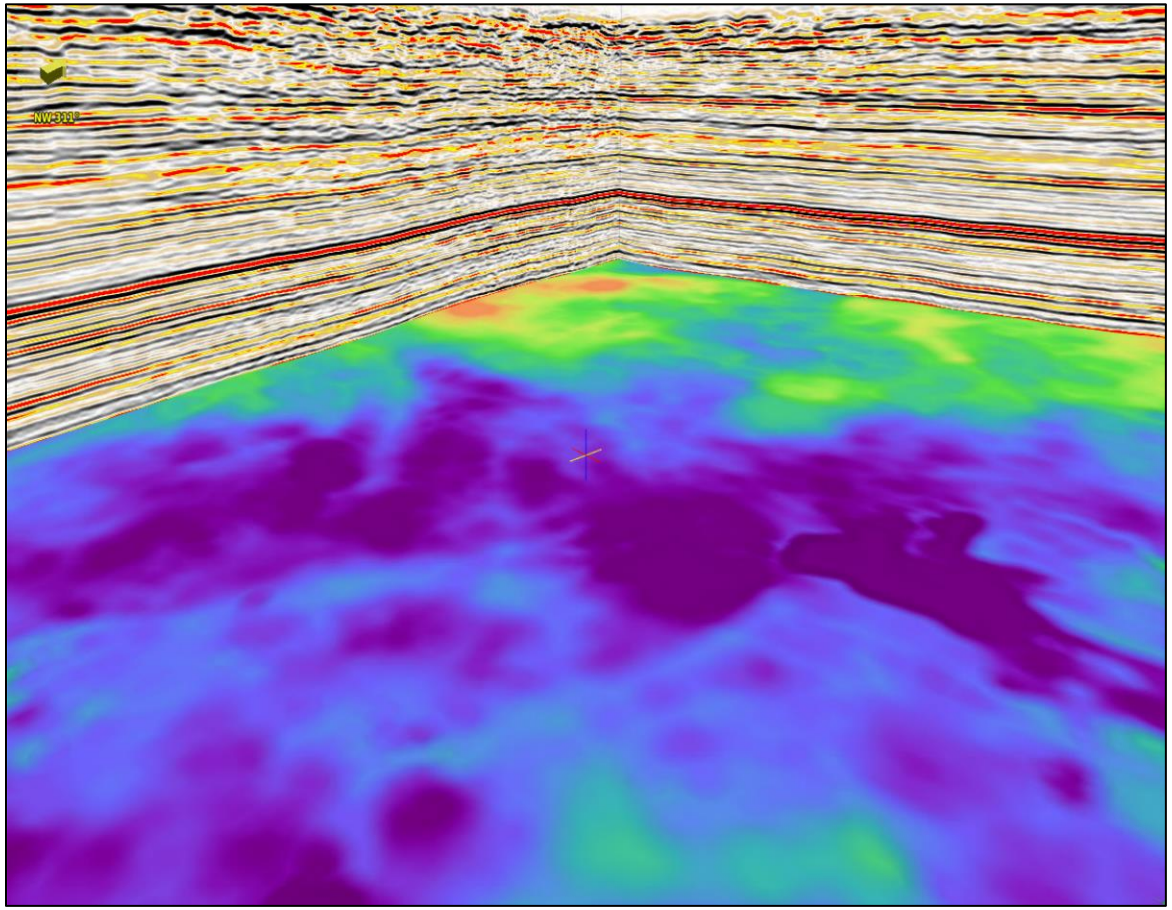
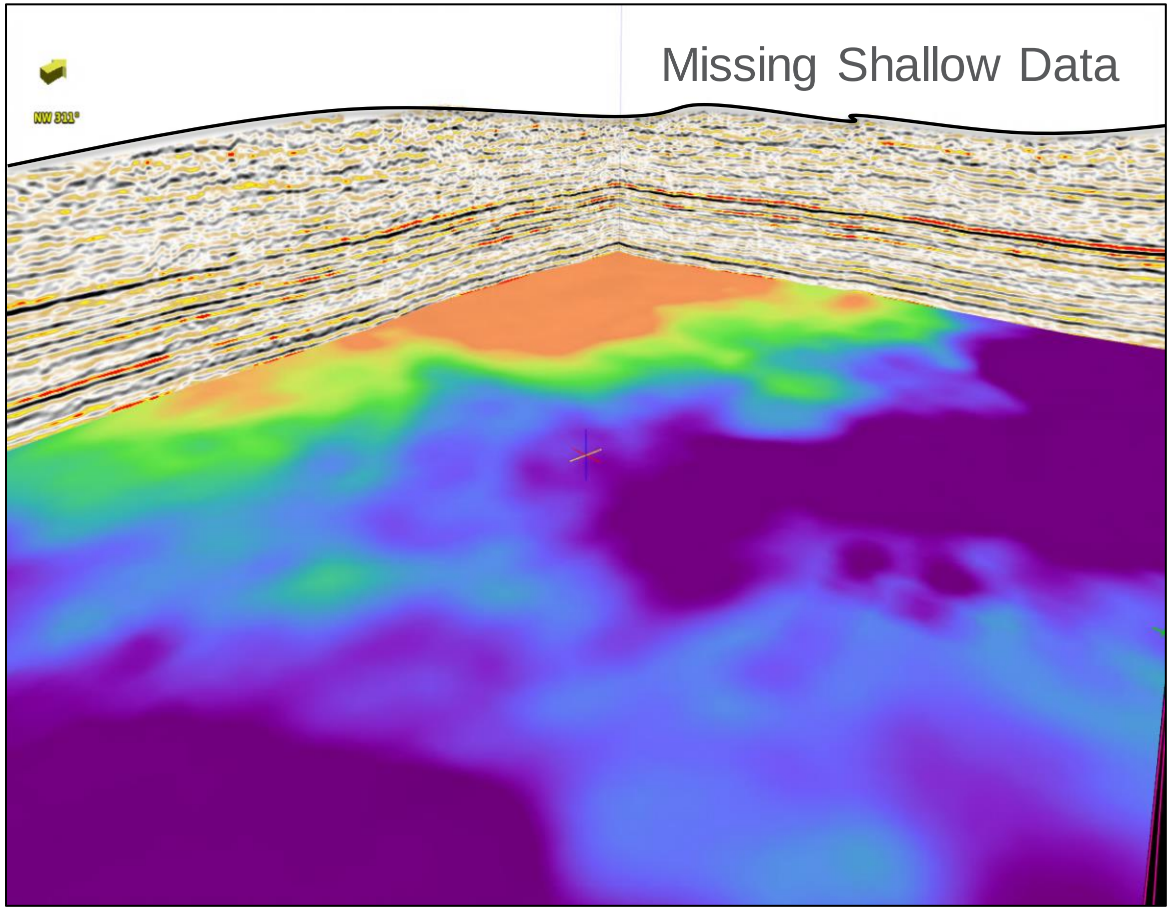
Grayburg Interpretation: HTD vs. Legacy

HTD



Legacy



Applications for HTD 3D Seismic Data

- Lateral resolution increases by 4x
- Signal-to-noise ratio increases
- Vertical resolution increases
- Better horizon picks
- Well planning and competitor analysis

What did we learn?

- Seismic data is the only data between any of the well data.
- Seismic data provides a picture of the all the subsurface.
  - NO other data samples the full volume subsurface.
- Seismic data identifies, measures and connects different types of data.
  - Well data
  - Drilling data
  - Petrophysical data
  - Completion data
- Seismic industry value add is to provide the data that connects all the different types of data to locate minimal number of wells in the best reservoir rock at the right spacing to produce the most hydrocarbons.

Exploration to Exploitation

References

- Alexandre Araman, Benoit Paternoster, Dmitry Isakov, and Natalia Shchukina, (2012), "Seismic quality monitoring during processing: what should we measure?," *SEG Technical Program Expanded Abstracts* : 1-5.https://doi.org/10.1190/segam2012-1044.1

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Thanks for Listening!

Questions?

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