North Sea 4D

Sima Daneshvar, Payson Todd

11/15/19

Project Summary

- **Area :** Edvard Grieg oil field, Norwegian North Sea

- **Data**

  - 2016 / 2018 OBC 3C 4D seismic data provided by Lundin Norway

  - 12 Wells

- **Primary Research Goals:**

  - Evaluate potential benefits of PS data in characterizing reservoir heterogeneity and effects of development with 4D Pre-stack Joint PP/PS Inversion – *April 2020 , Sima Daneshvar*

  - Evaluate use of PP/PS HTI Anisotropy inversion for Geomechanics and Well Planning - *January 2021, Payson Todd*

  - Dynamic Reservoir Properties from Pre-Stack Joint PP/PS Inversion, Constrain and Update Simulation Model - *December 2021, Payson Todd*

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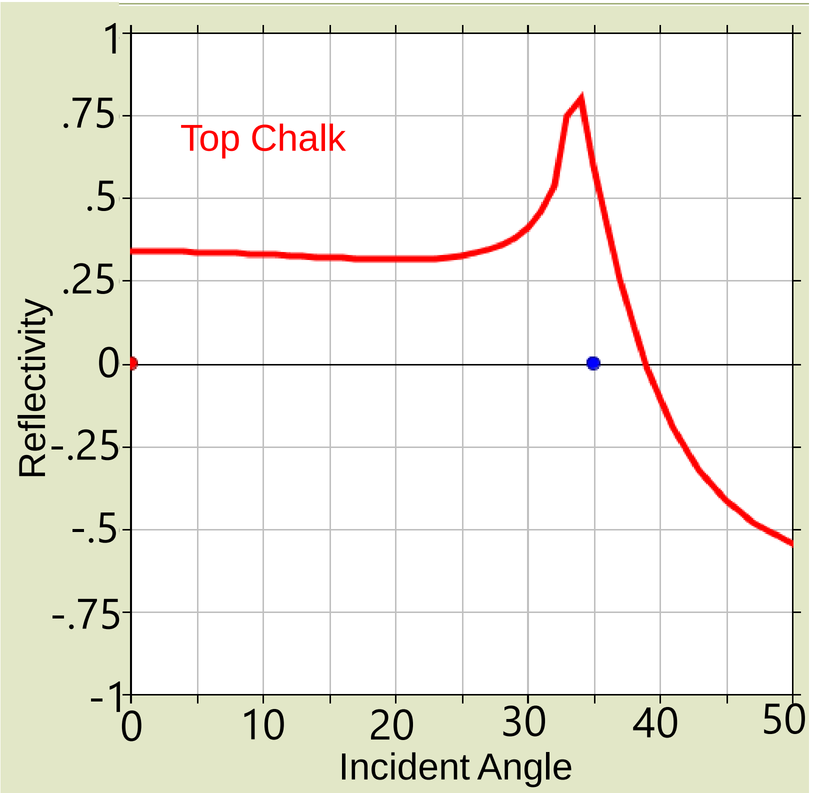
4D Simultaneous PP-PS Prestack Inversion

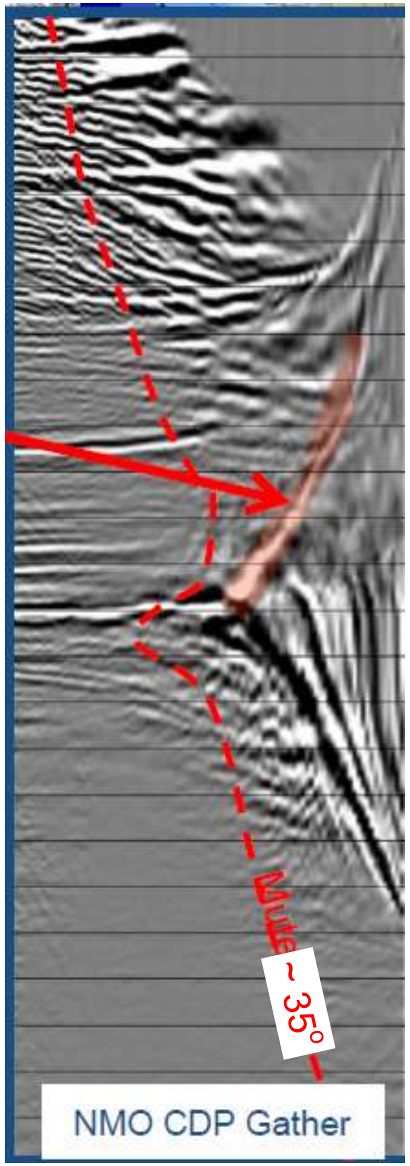
Motivation: Allows more reliable extraction of P-impedance, S-impedance, and potentially density.

Using only PP waves, good quality data at large angles are needed for a reliable S-impedance inversion or possibly density inversion, challenging particularly due to critical reflection at top chalk layer.

Goal: Improved static and dynamic reservoir model

Scenario	Detail	AI change %	PR change %
4. Pressure drop with gas breakout	Pressure down 500 psi, gas saturation 5%, max sensitivity, aeolian reservoir	-3	-12





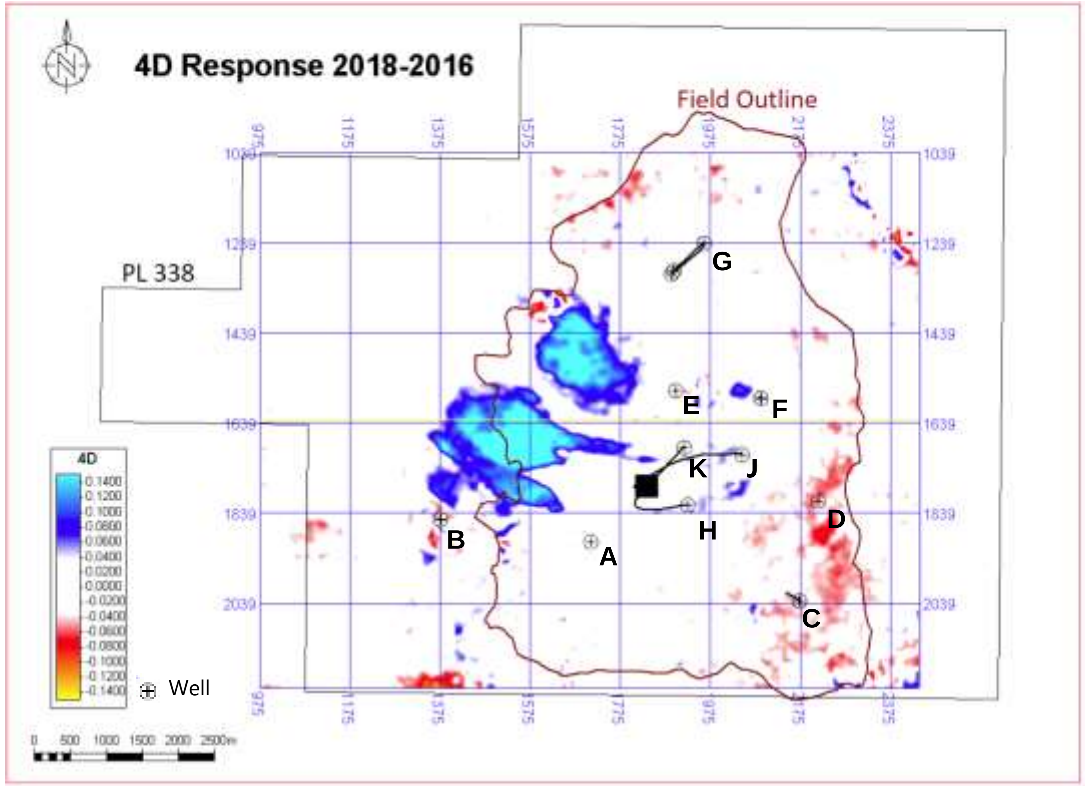
Watts et al., 2016

Project Workflow

- Quality Control
- Post-Stack Inversion
- PP Pre-Stack Inversion
- PS Pre-Stack Inversion
- Registration
- PP-PS Joint Inversion
- 2018-2016 Difference Inversion

RCP
In pursuit of new ideas

Motivation: Evaluate potential benefits of PS data in characterizing ***reservoir heterogeneity*** and ***response to development***



Outline

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  - Amplitude QC
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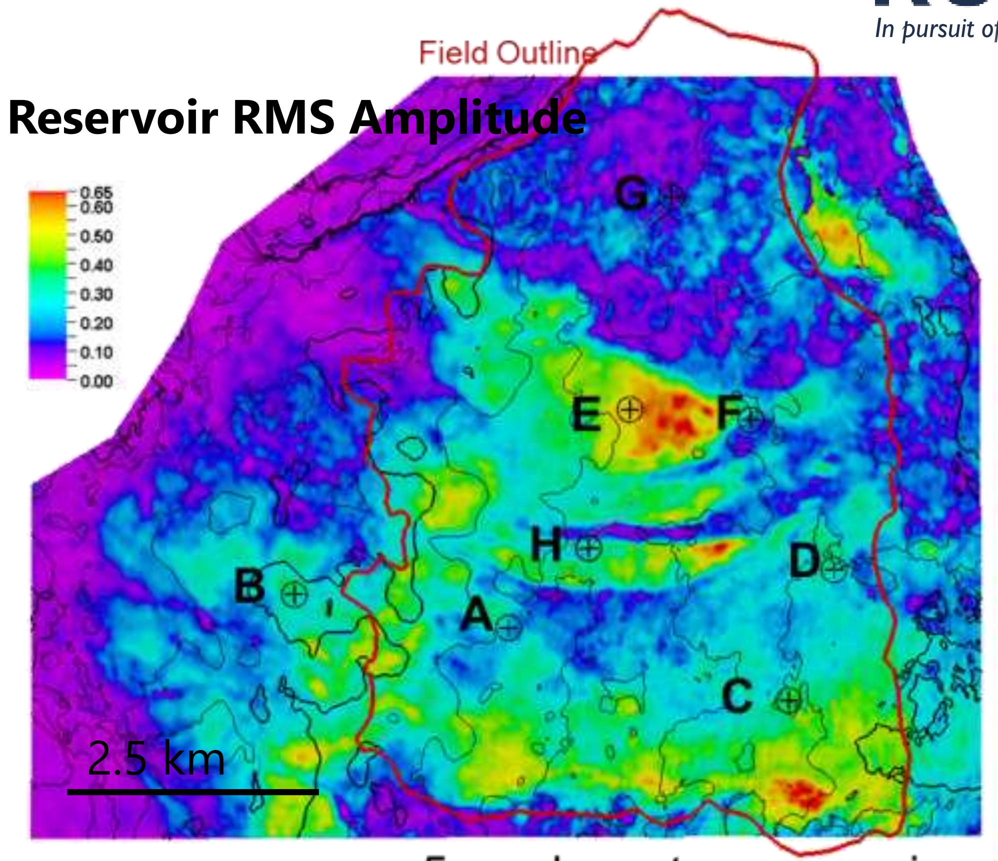

5ms above top reservoir,
30ms below*

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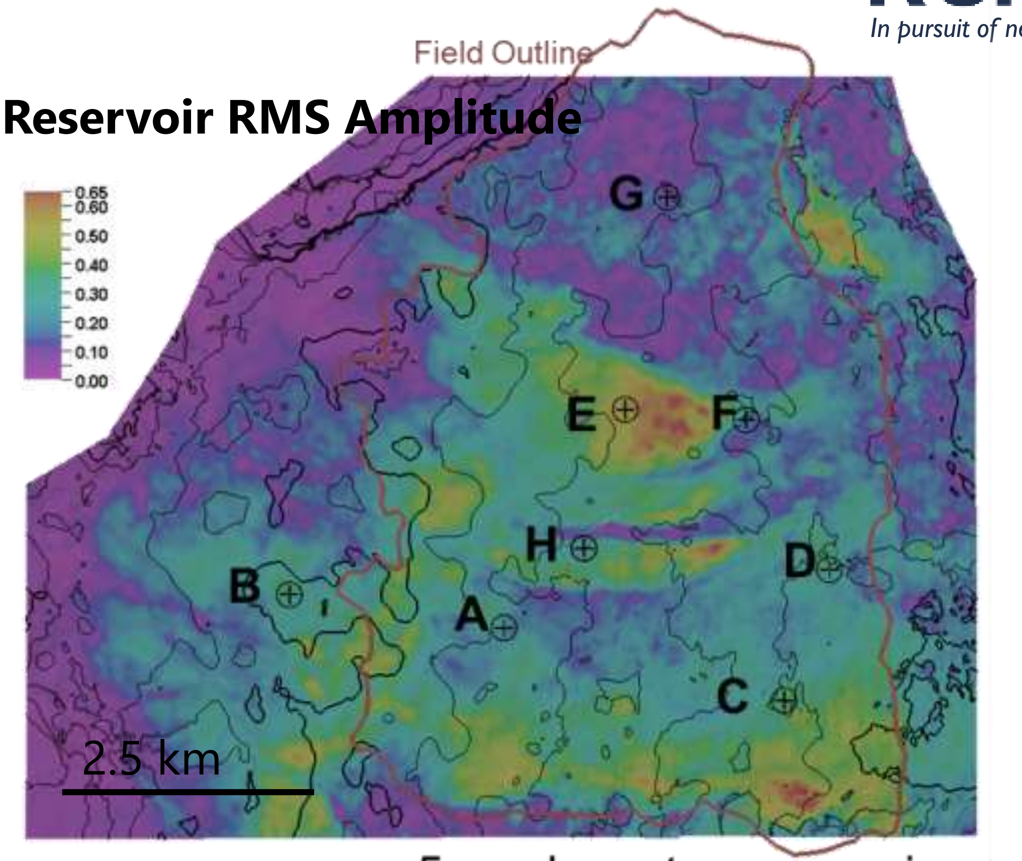
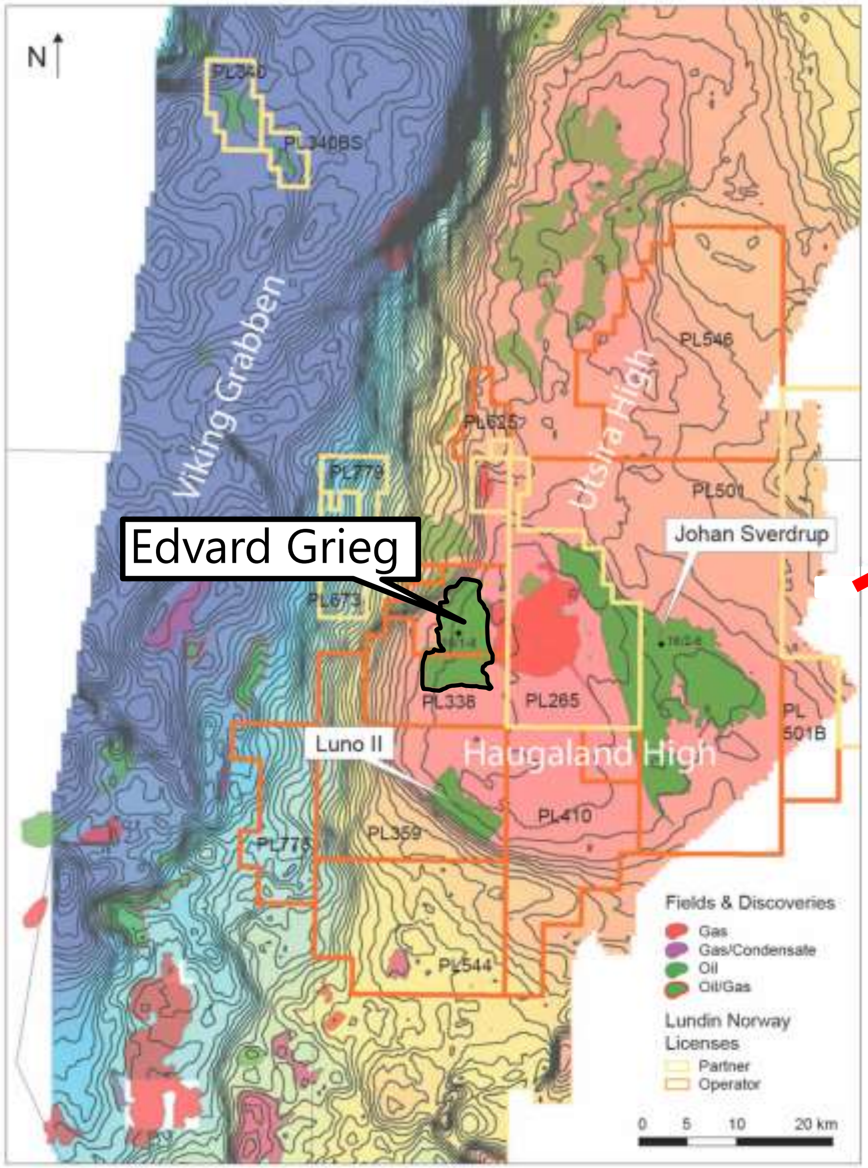
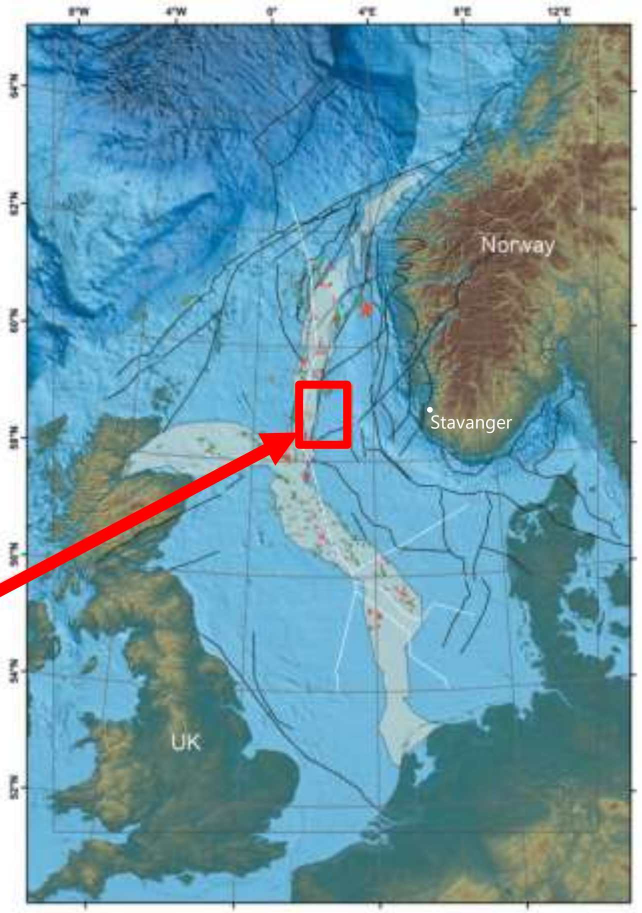
Reservoir RMS Amplitude



5ms above top reservoir, 30ms below*

Norwegian North Sea: *Edvard Grieg Field*



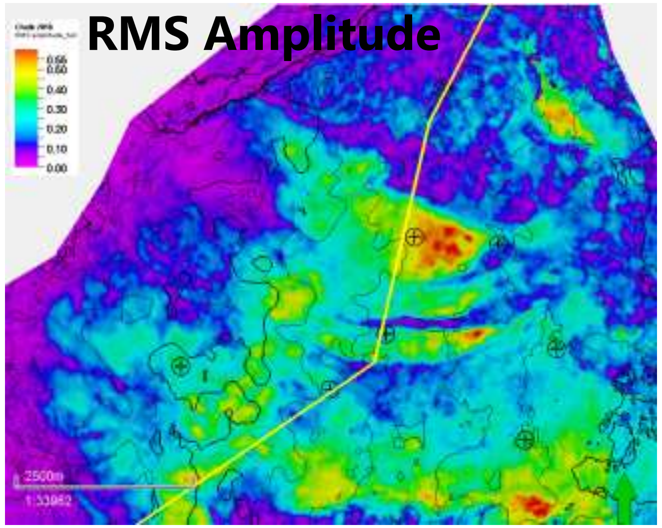


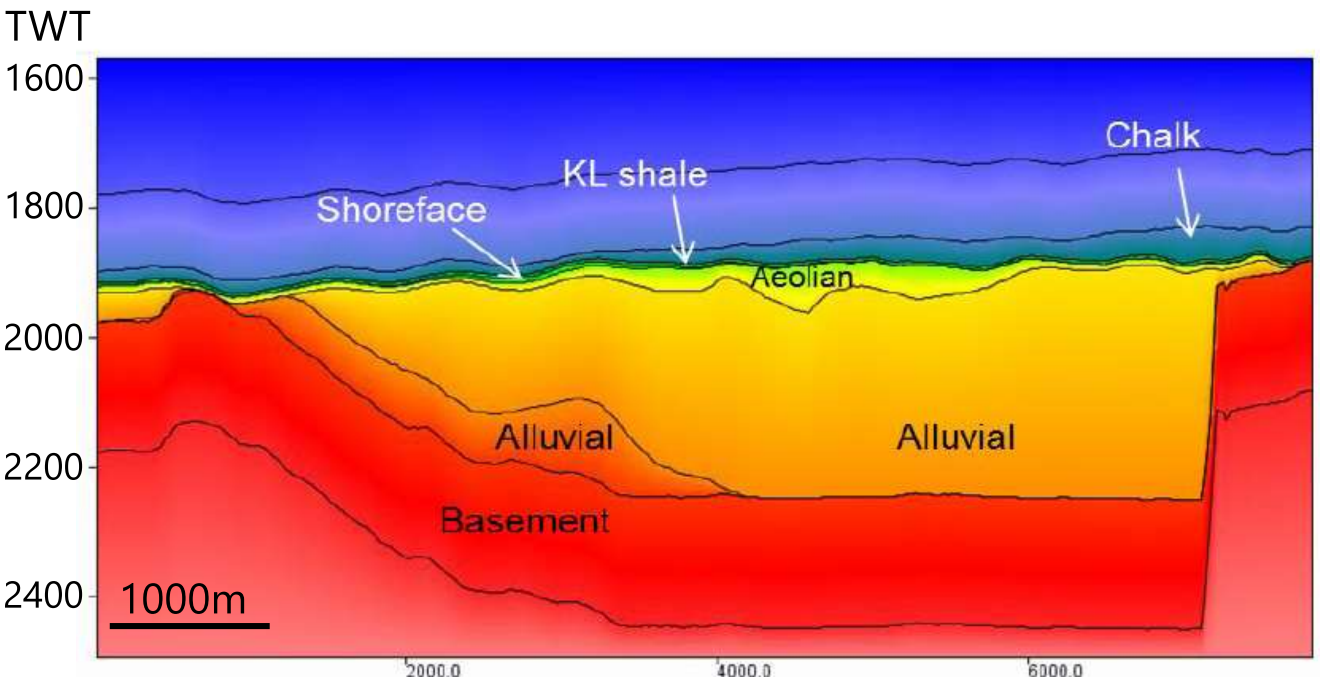
- 180 km west of Stavanger in PL338.
- ~40 m (131 ft) column
  - undersaturated light oil with a GOR of around 702 SCF/BBL
- Field Timeline
  - 2007: Discovered
  - 2015: Began Production
  - 2016: Water injection
- Operator: Lundin Norway

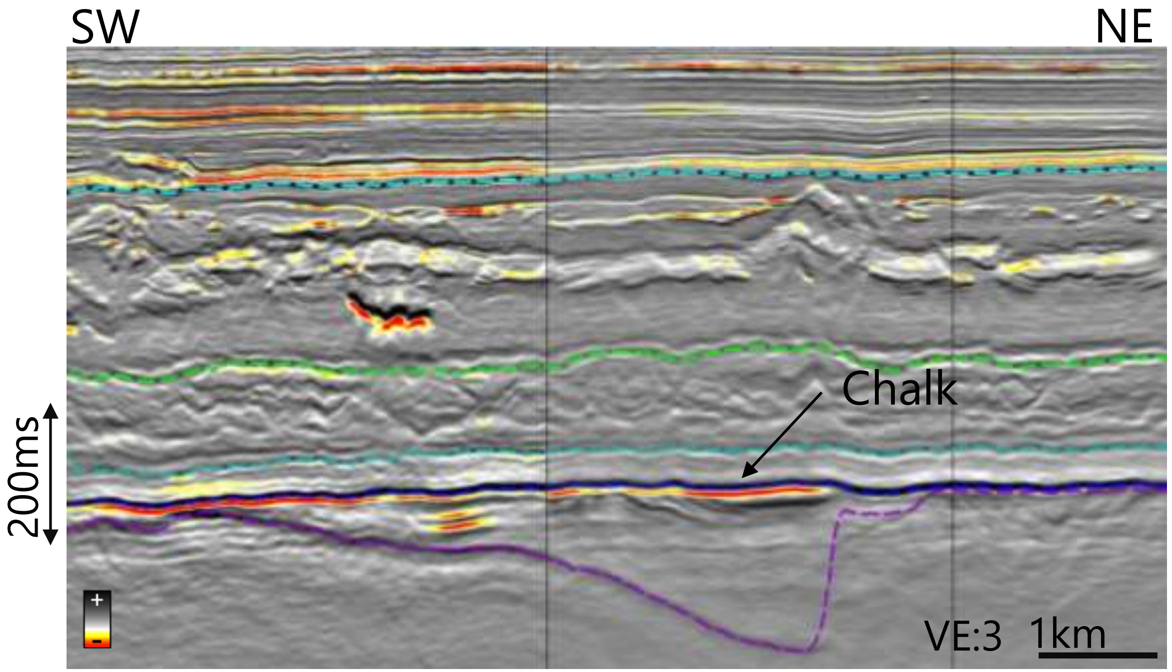
Rønnevik 2017

Reservoir Architecture

- Multi-Source Reservoir: aeolian sands, alluvial sands and conglomerates, and shelfal sands
  - Aeolian sand holds more than 50% of reserves
  - Multi-Darcy permeability in aeolian, up to hundreds of mDarcy permeability in alluvial
- Overlain by high velocity Shetland Chalk

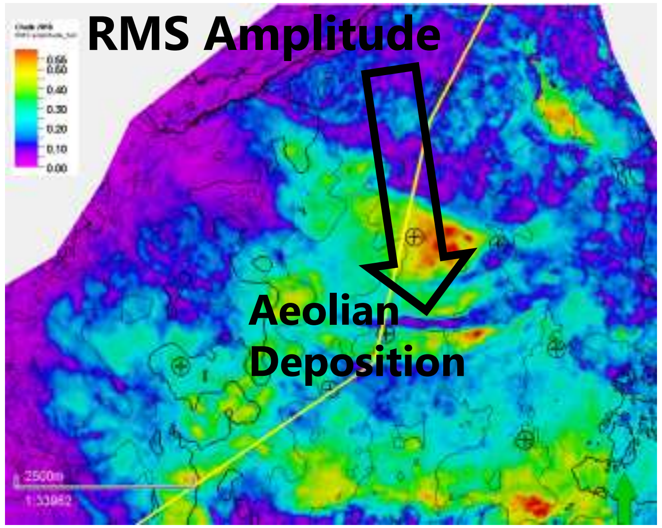






Watts et al. 2016

Reservoir Architecture



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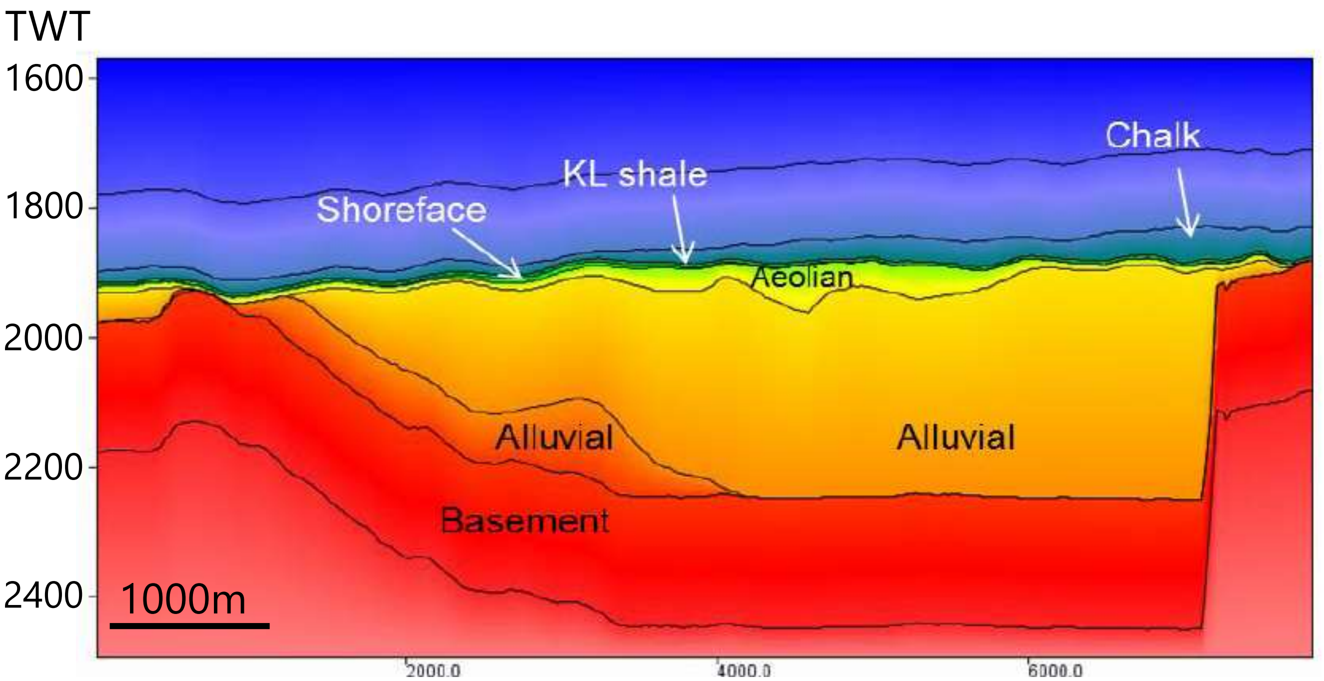

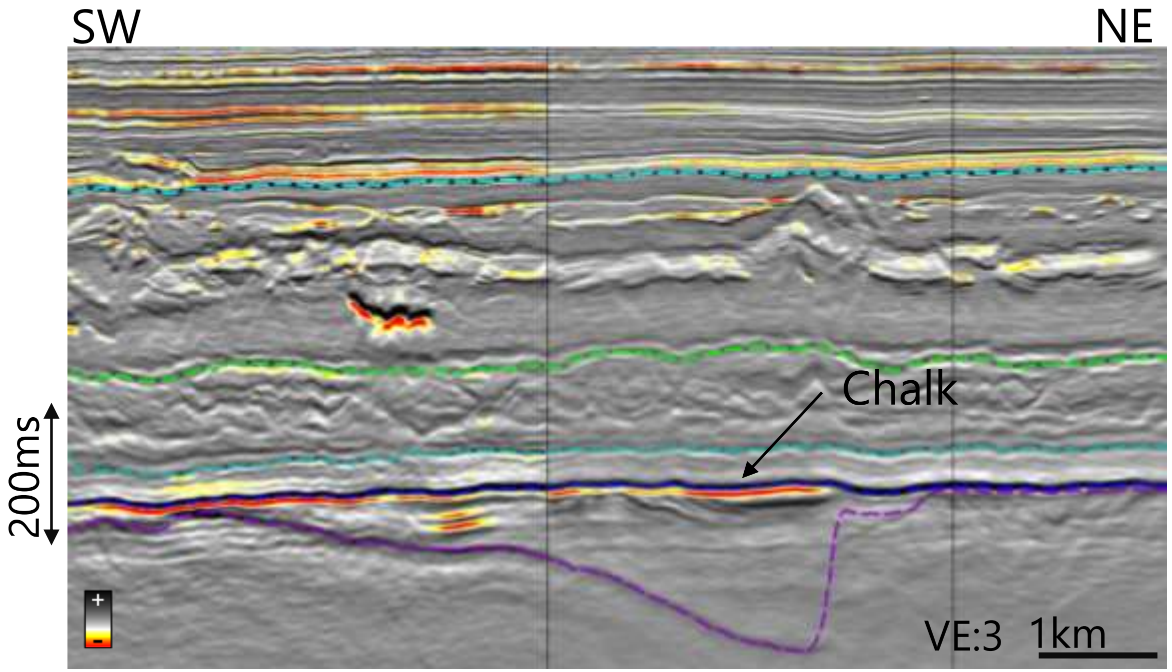

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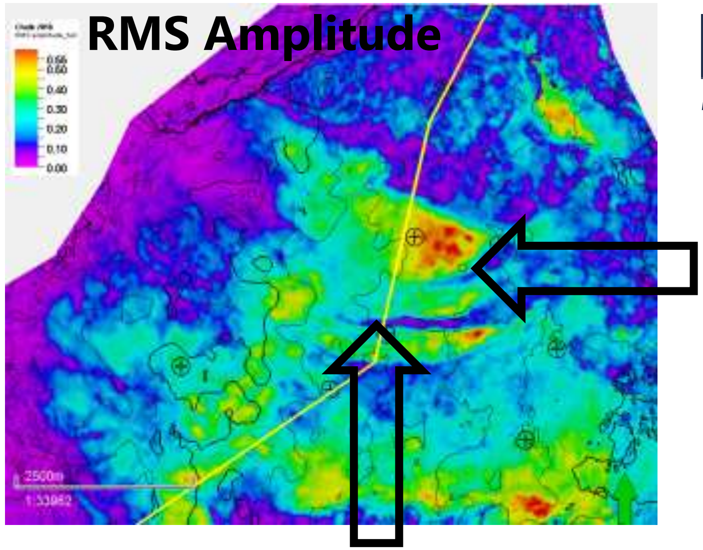
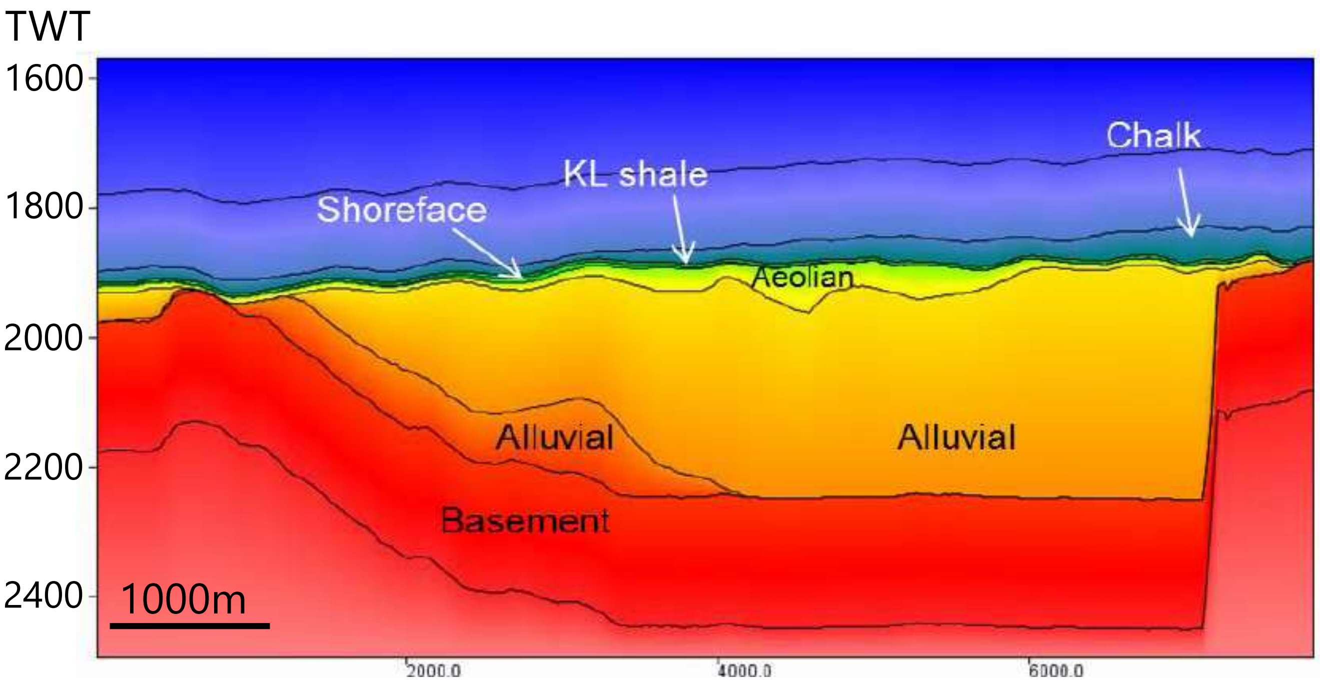
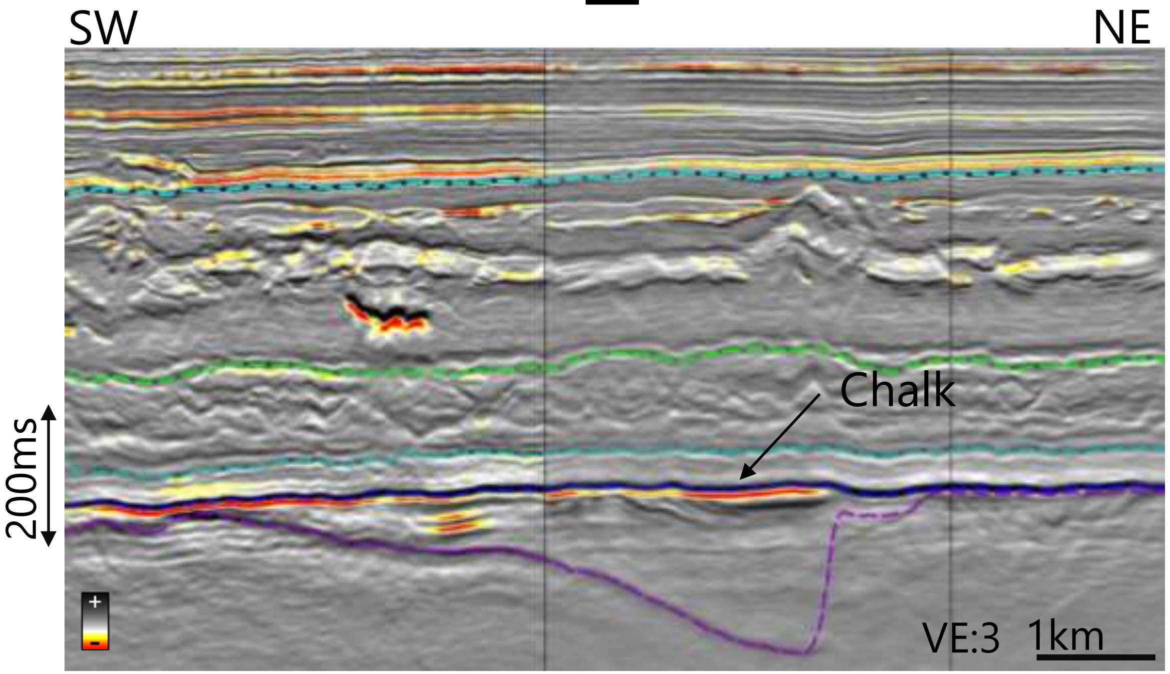


Alluvial Deposition





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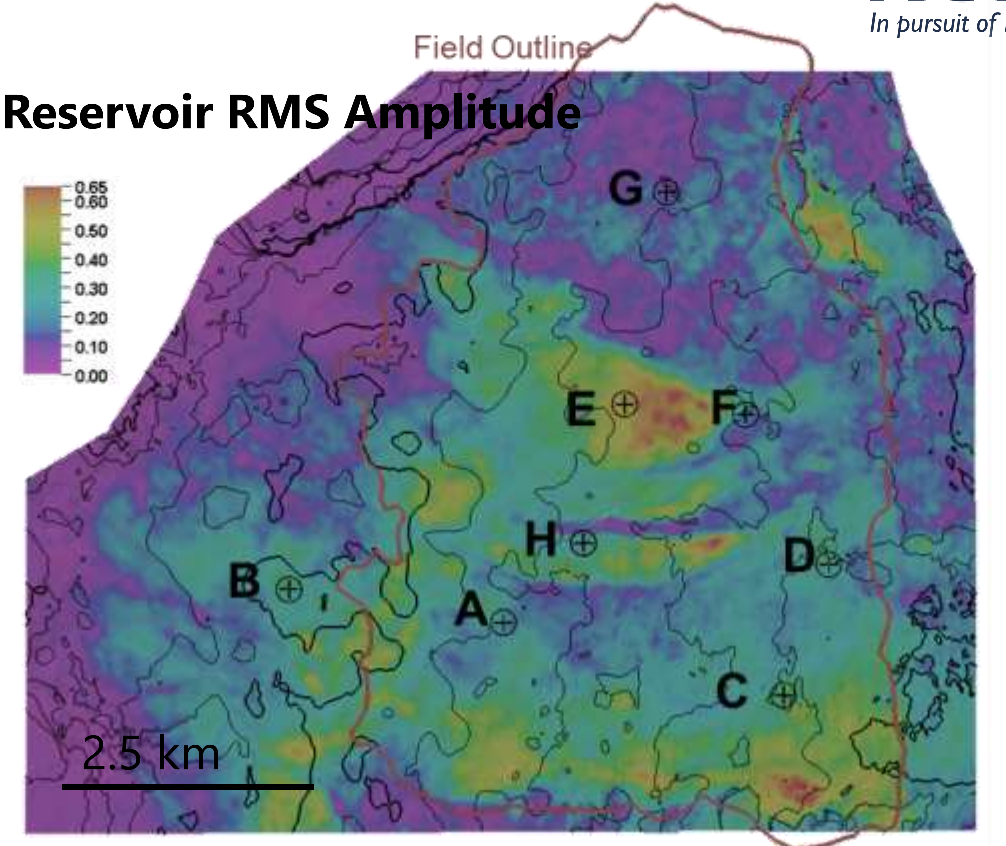
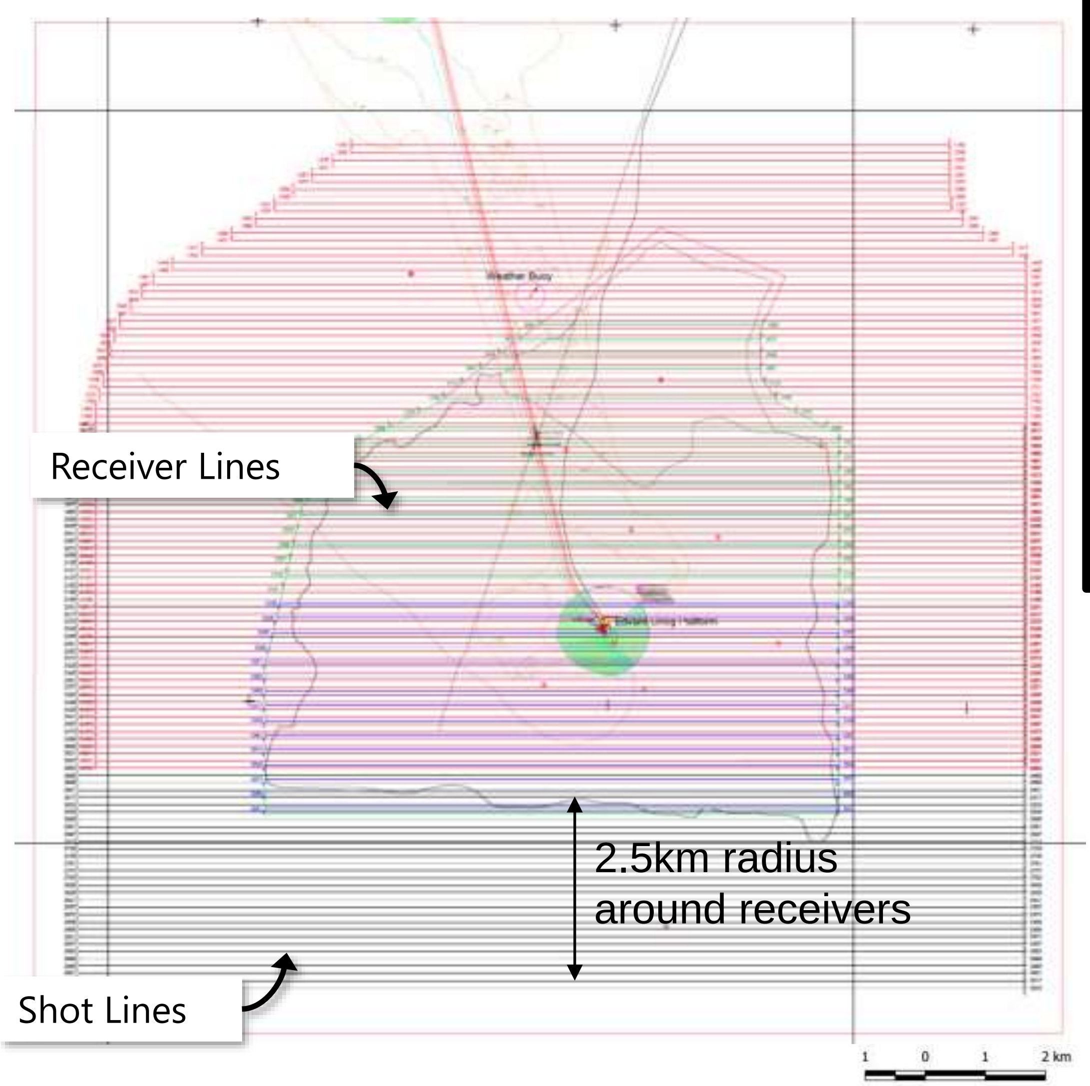
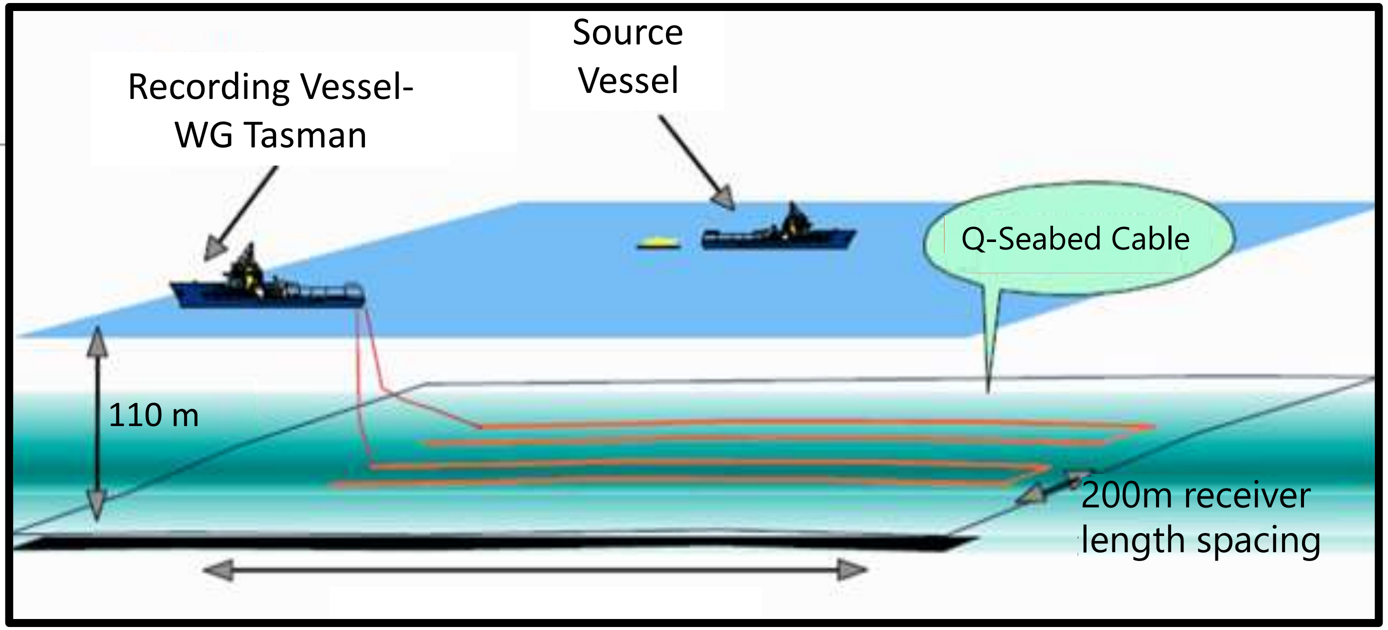


5ms above top reservoir, 30ms below*

2016 / 2018 4D OBC survey





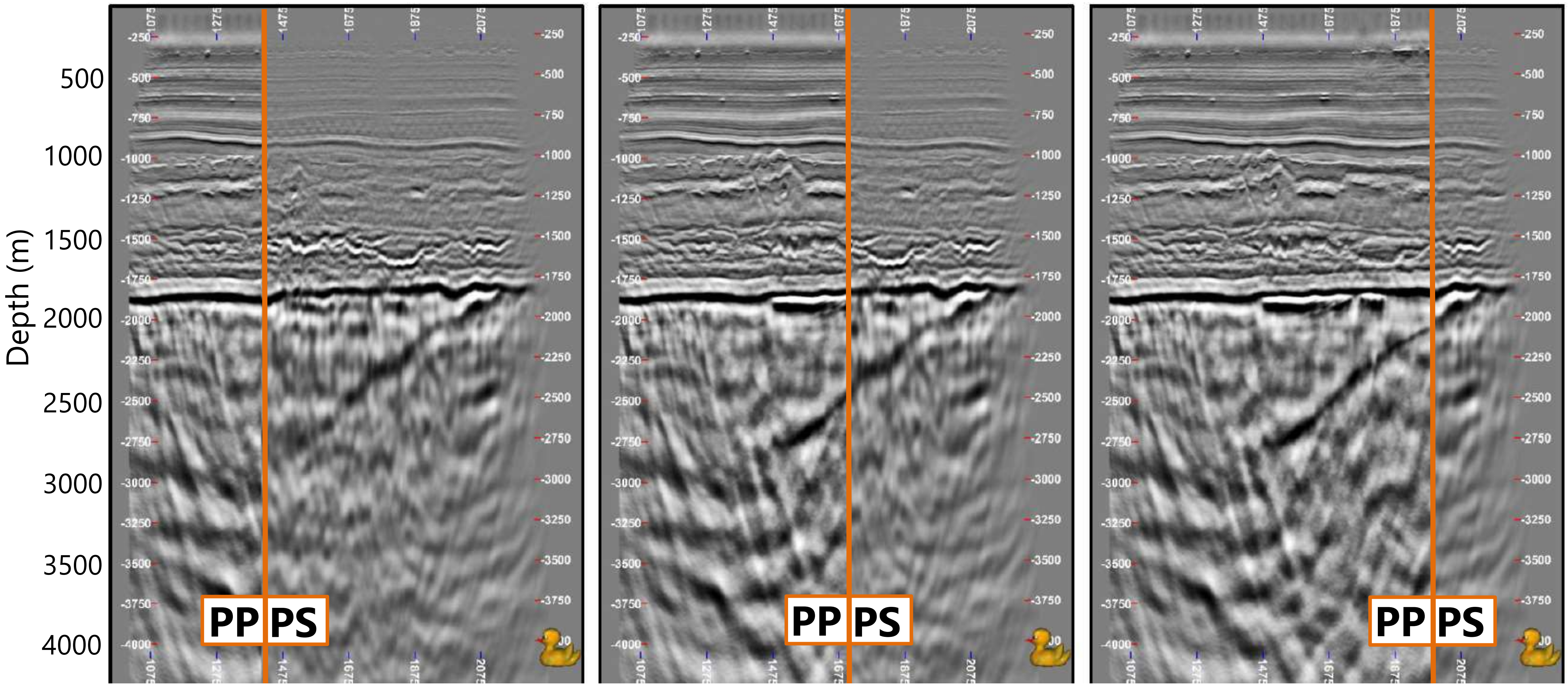
Baseline: Sept/October 2016 *(9m prod, start water injection)*
Monitor: Sept/October 2018 *(2.5y prod, 2y water injection)*

Area (km^2)	62
Group interval (m)	25
Receiver line separation (m)	200
Shot-point interval (m)	25
Source Line Spacing (m)	50
Full Azimuth	

WesternGeco, 2018

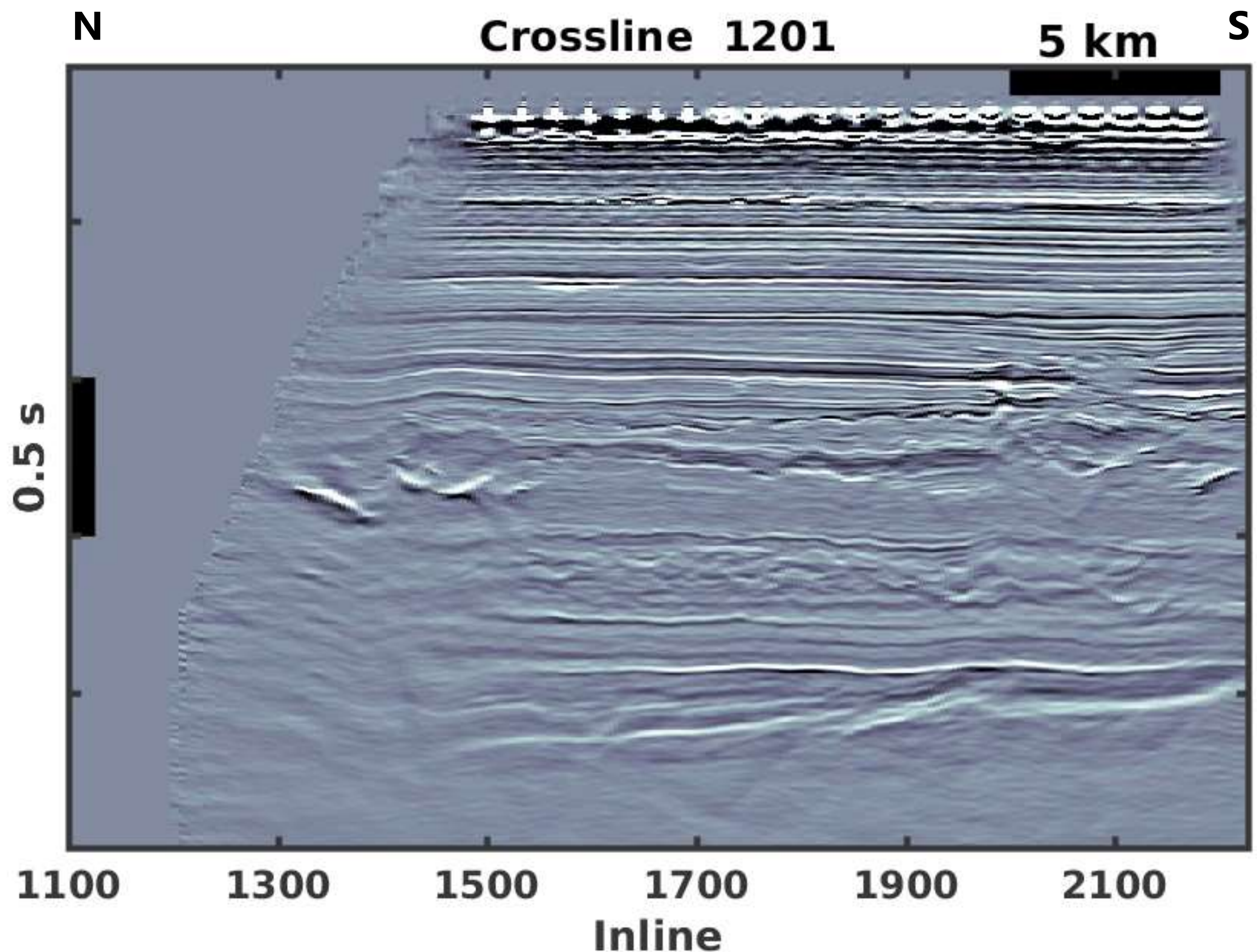
PS Data

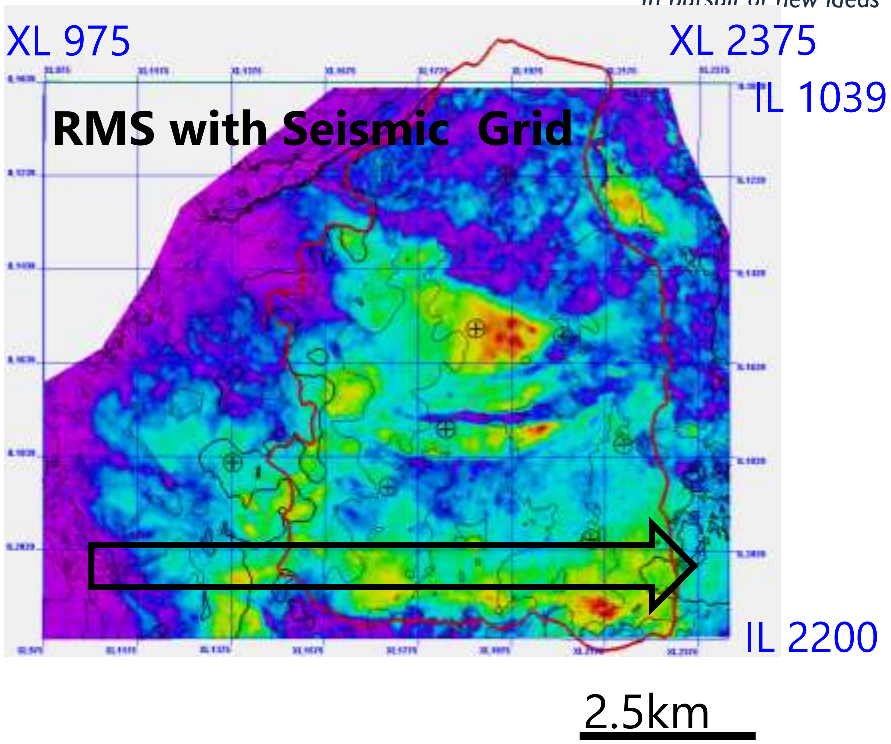
RCP
In pursuit of new ideas



Whitebread 2018

Sweep Through PP Stack Data





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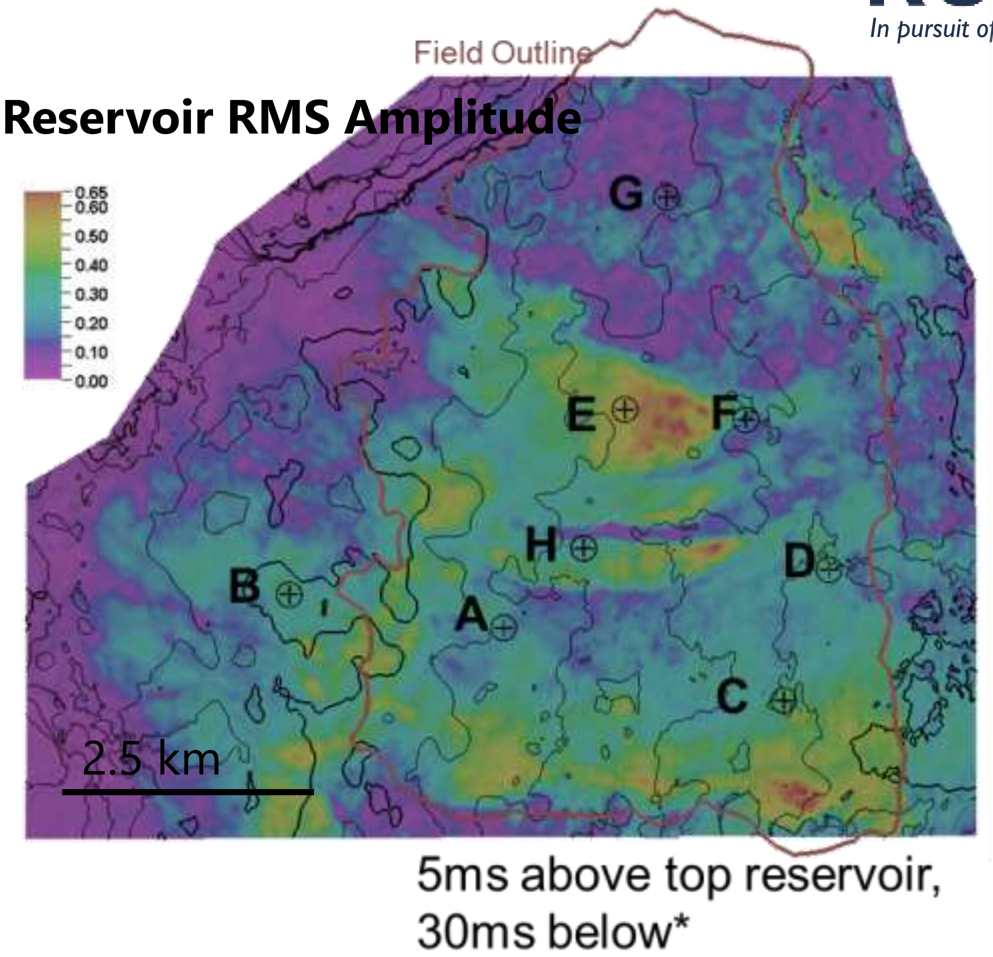
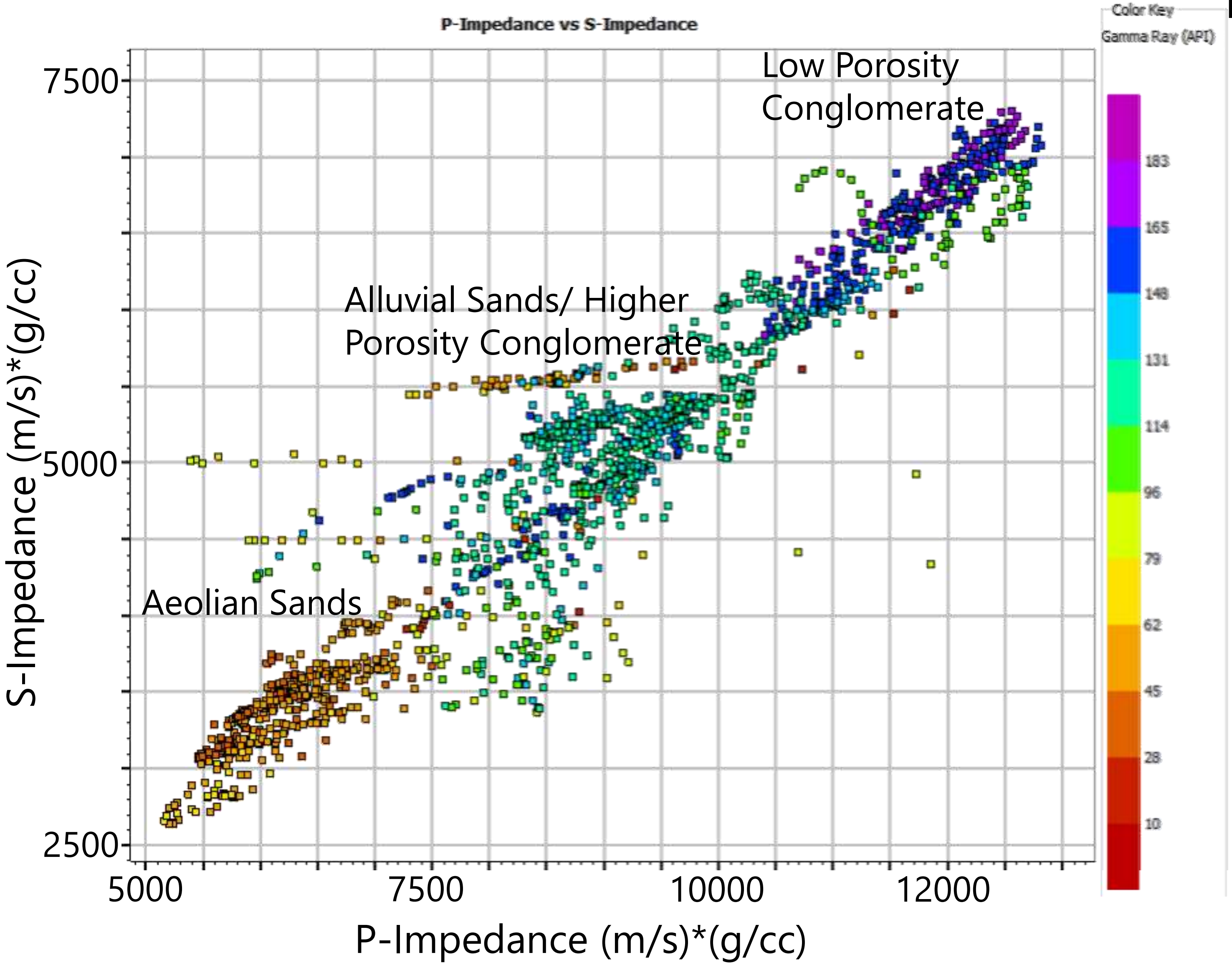
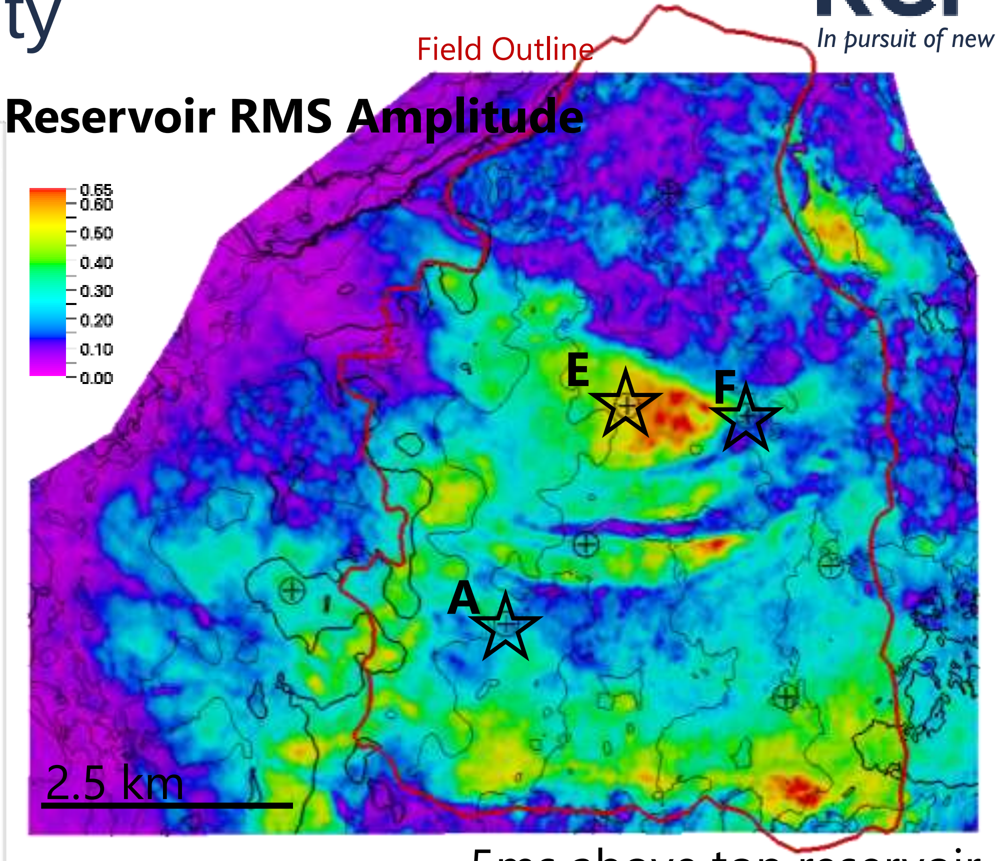


Rock Physics Approach: Facies Separability





5ms above top reservoir, 30ms below*

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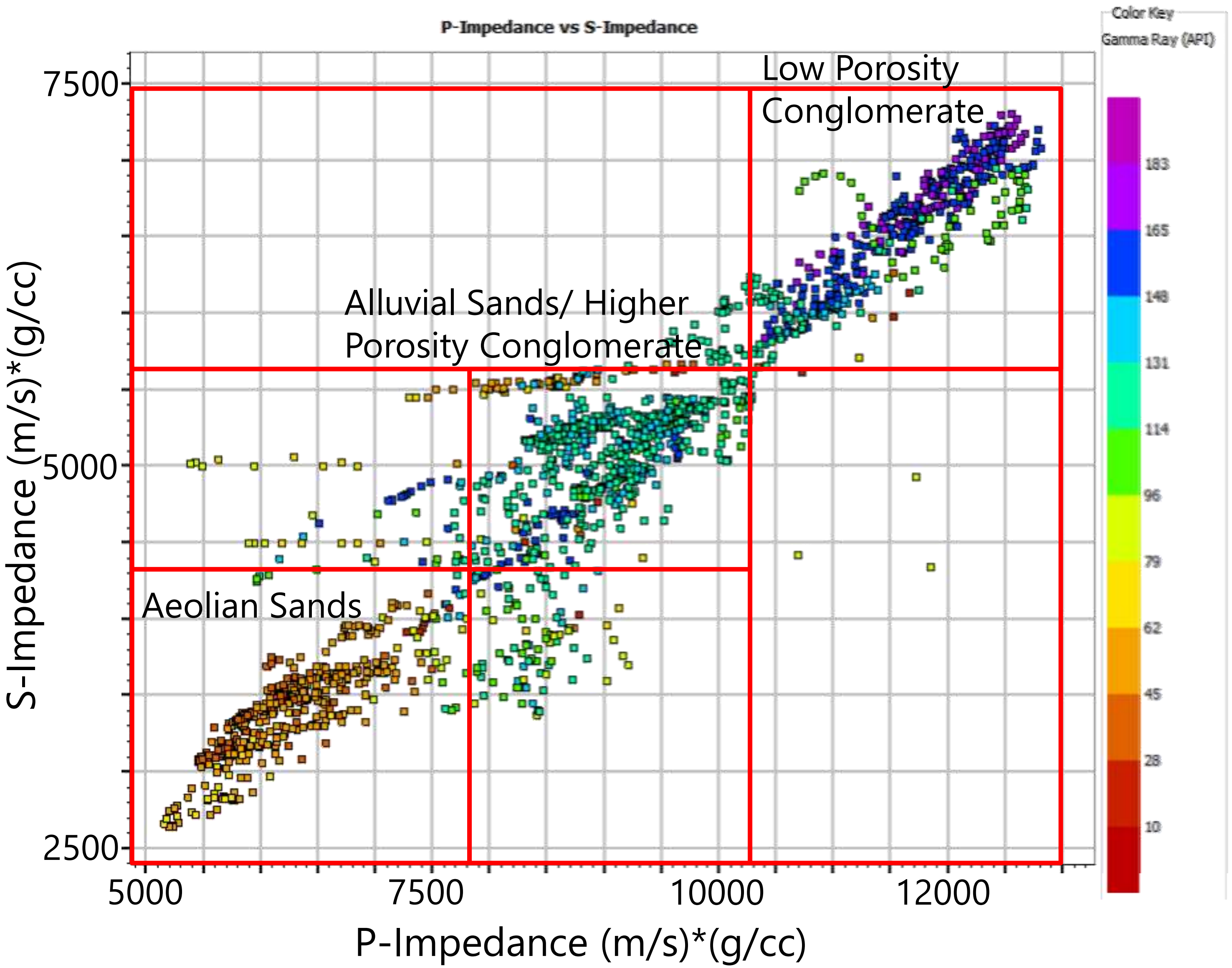
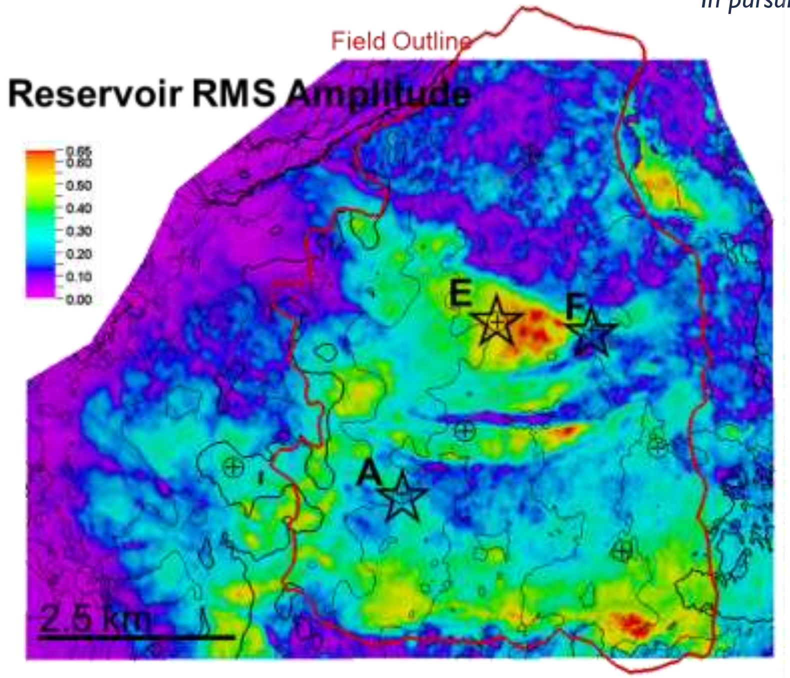
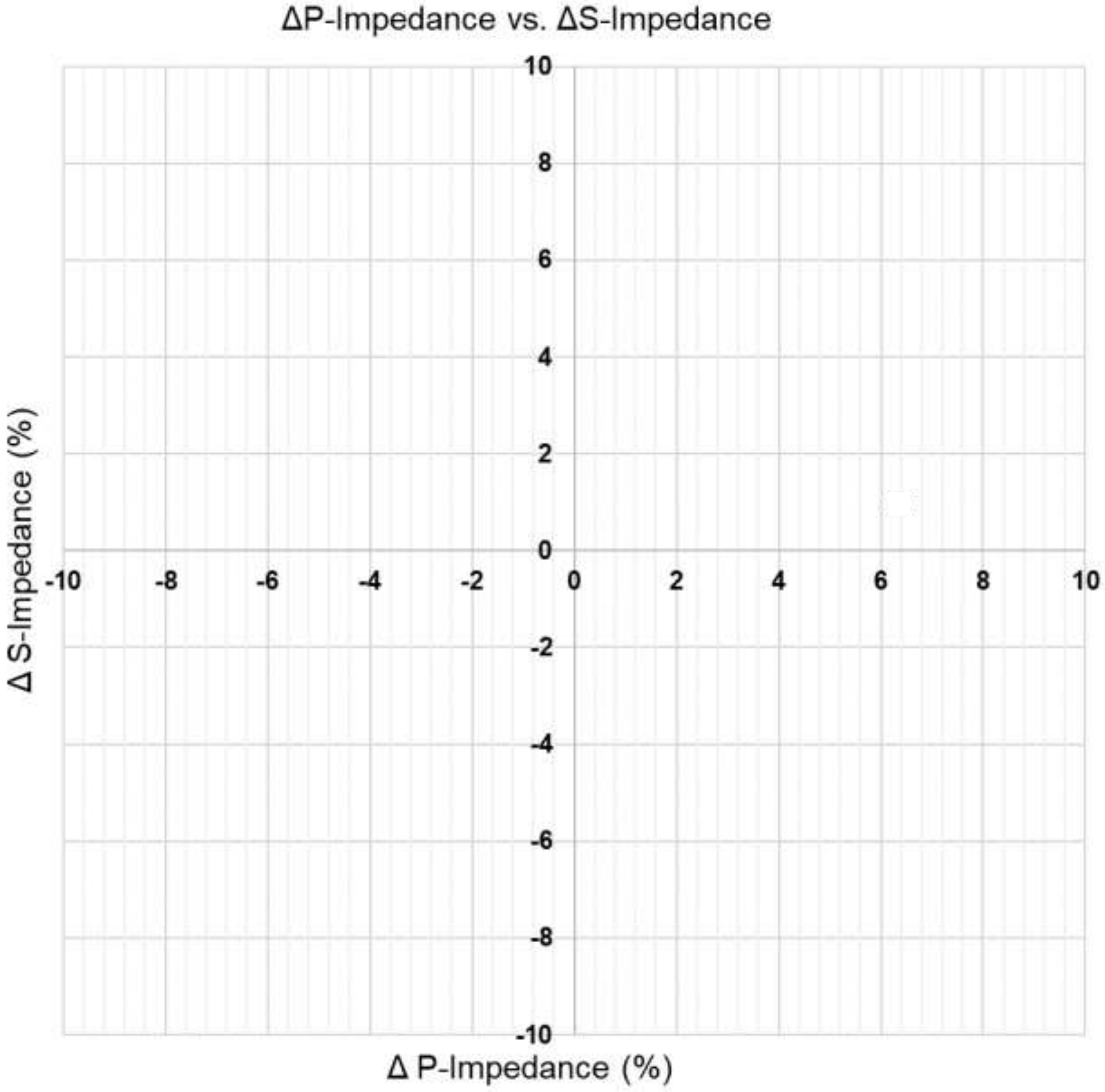
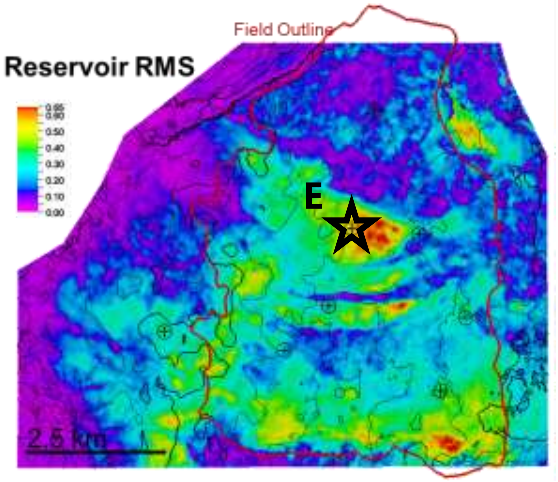




- Findings:
  - Facies are separable in using P-Impedance and S-Impedance *in well log domain*
  - Improved S-Impedance can be used to *better constrain* facies identification in reservoir

Rock Physics Approach: 4D Response in Aeolian Reservoir





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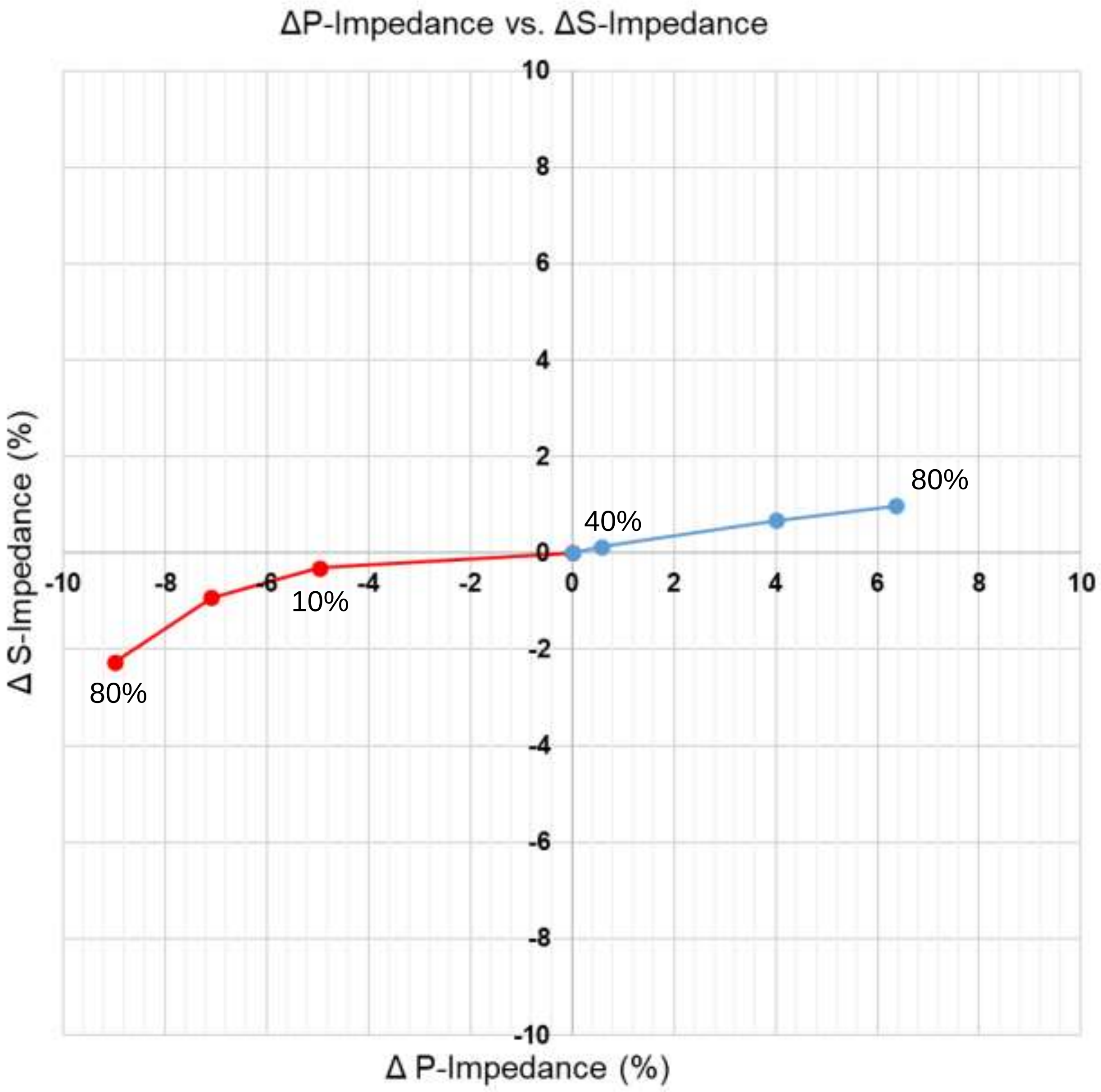
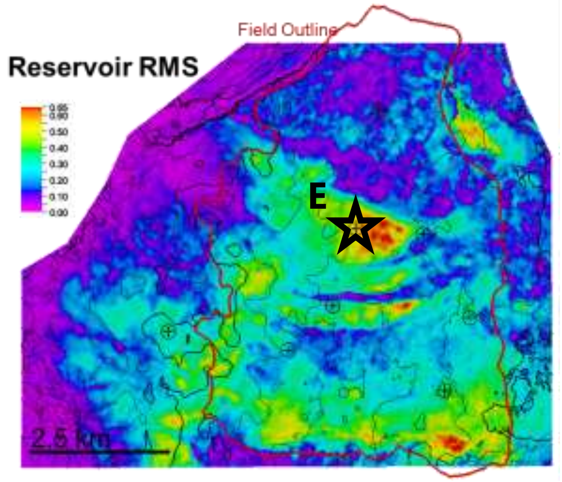


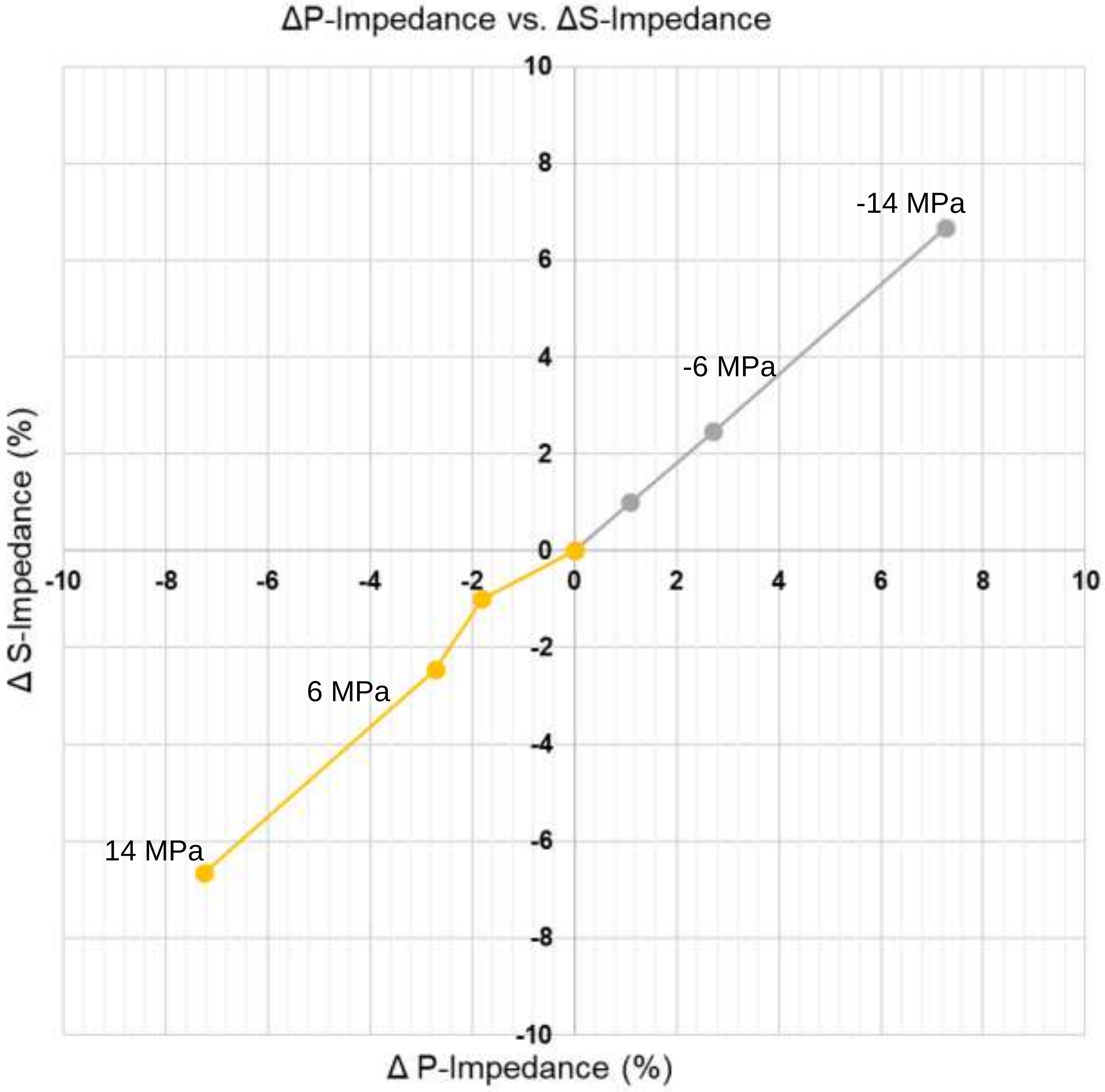


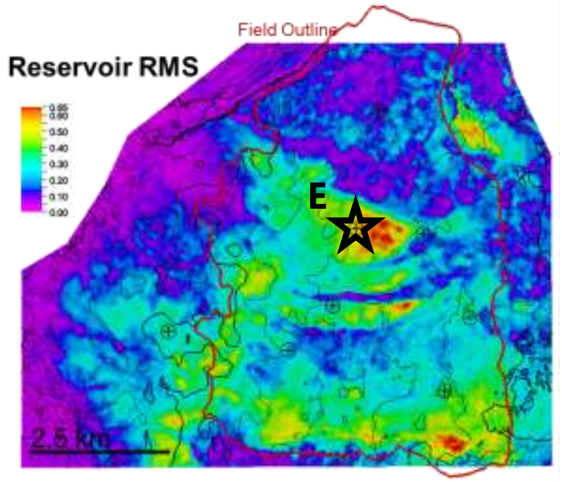
Saturation Changes

Gas Saturation

Water Saturation

Rock Physics Approach: 4D Response in Aeolian Reservoir



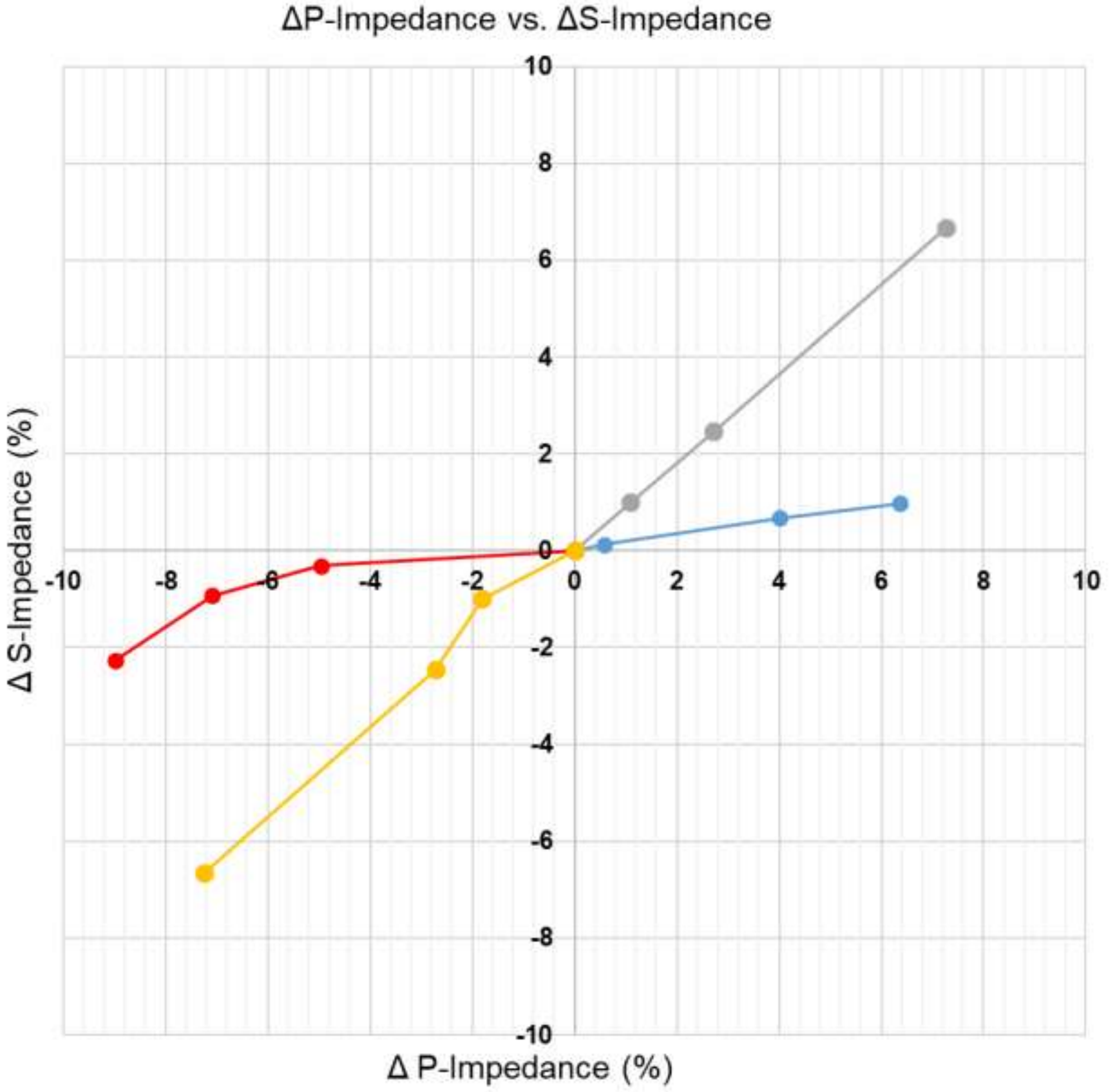


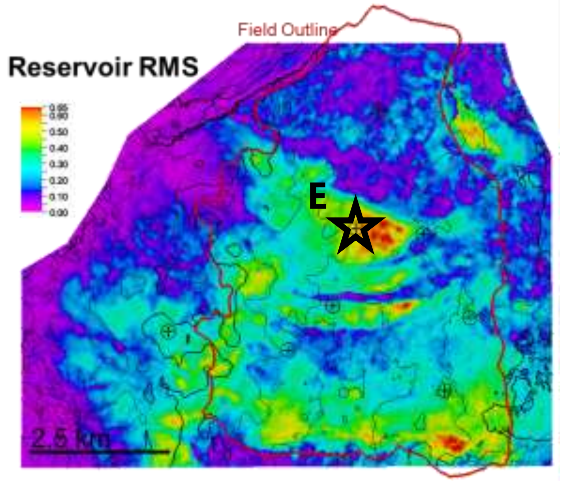
Pressure Changes

Pore Pressure Decrease

Pore Pressure Increase

Rock Physics Approach: 4D Response in Aeolian Reservoir

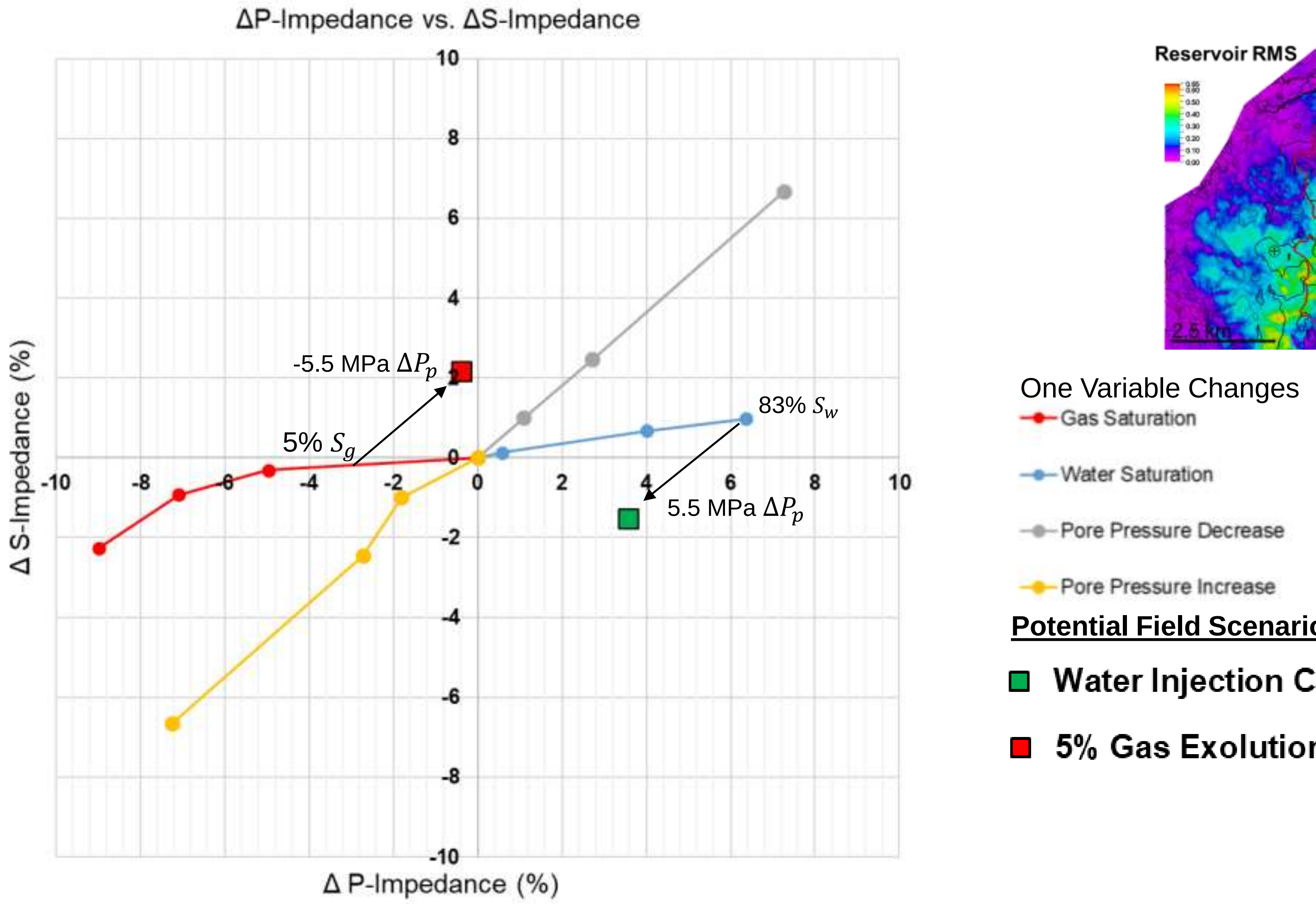


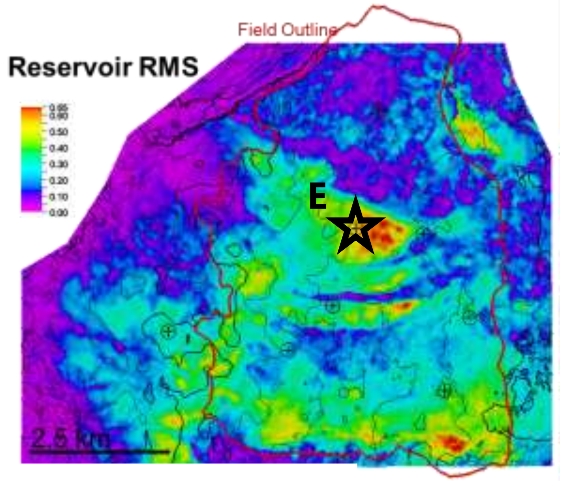


One Variable Changes

- Gas Saturation
- Water Saturation
- Pore Pressure Decrease
- Pore Pressure Increase

Rock Physics Approach: Saturation + Pressure Change Scenarios





Potential Field Scenarios

- Water Injection Case
- 5% Gas Exolution Case

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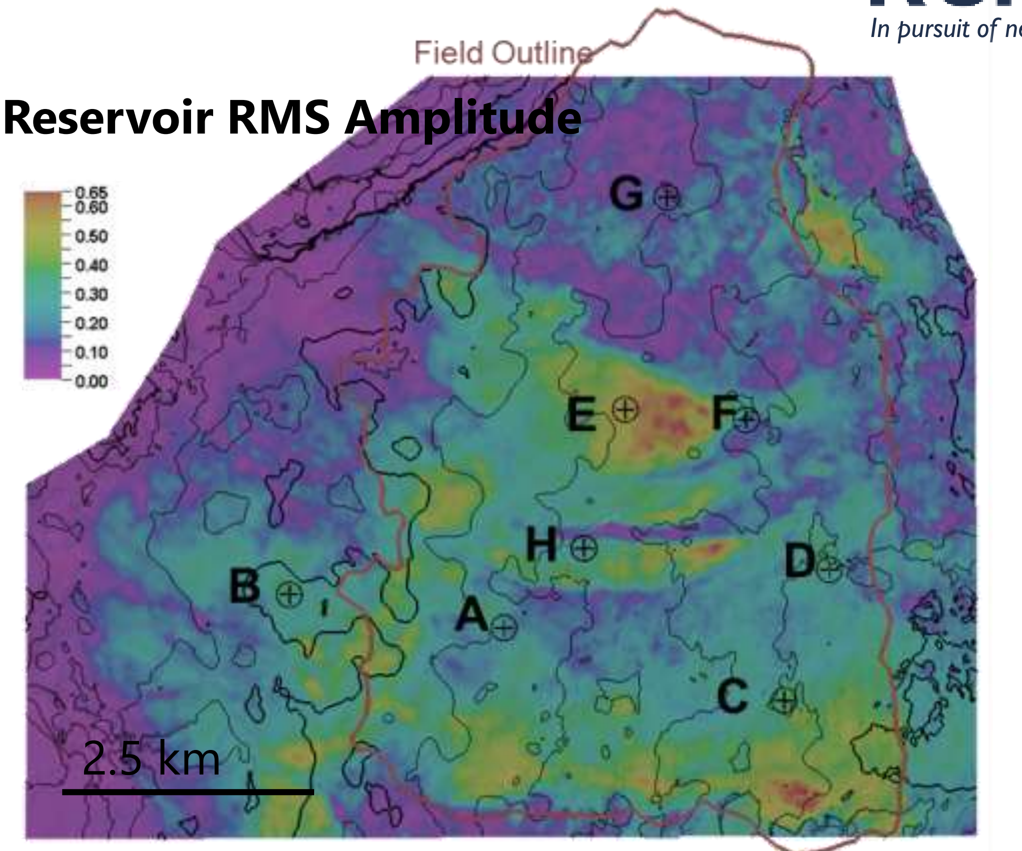
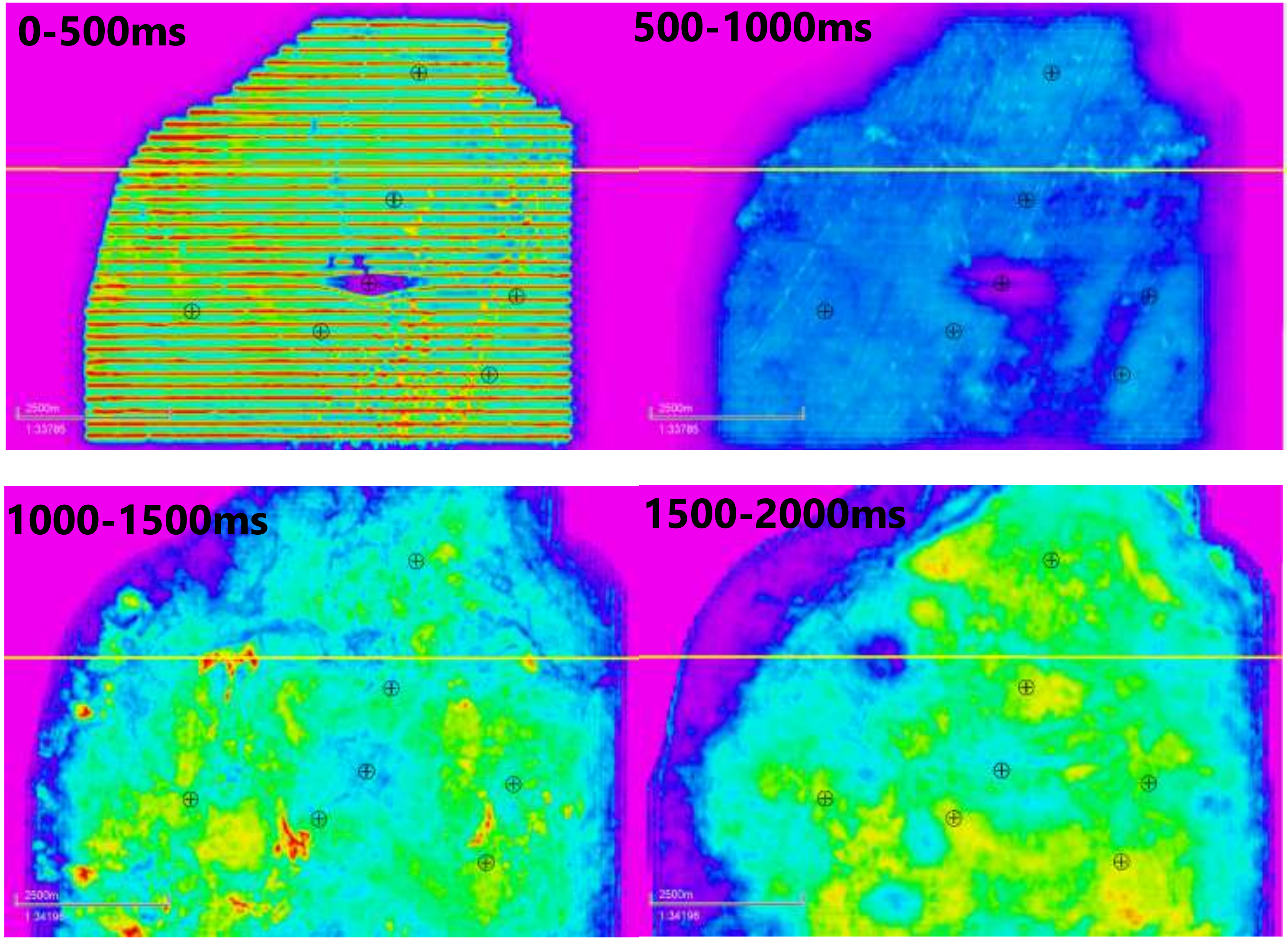
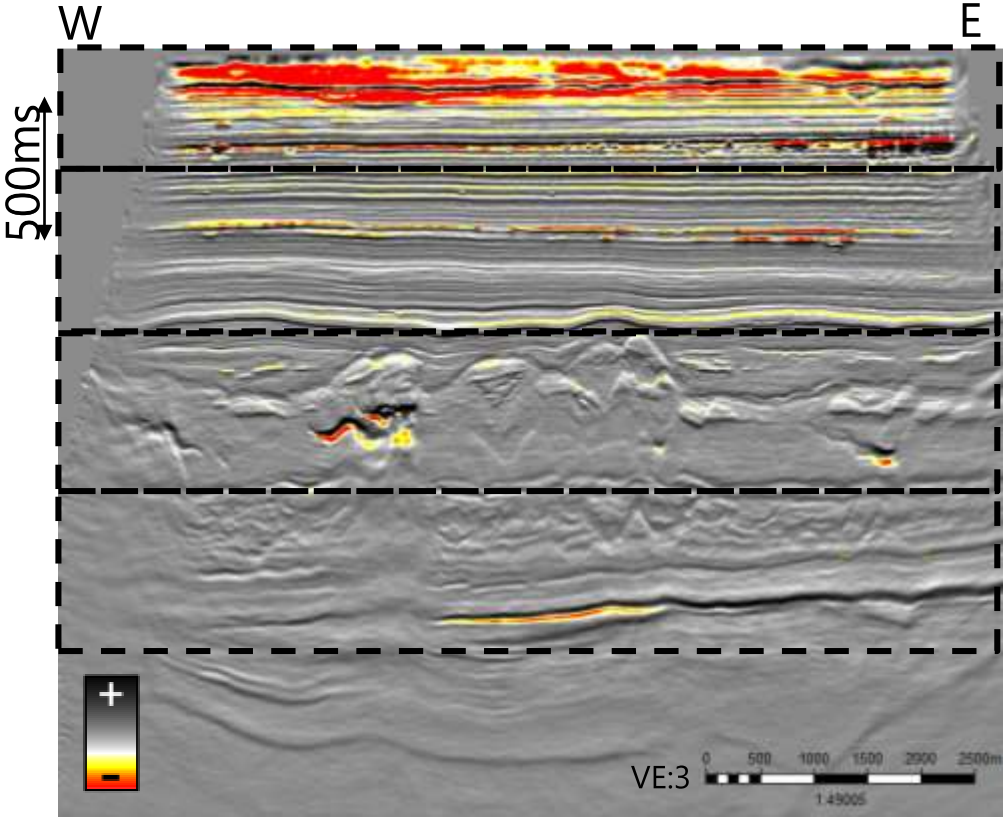


5ms above top reservoir, 30ms below*

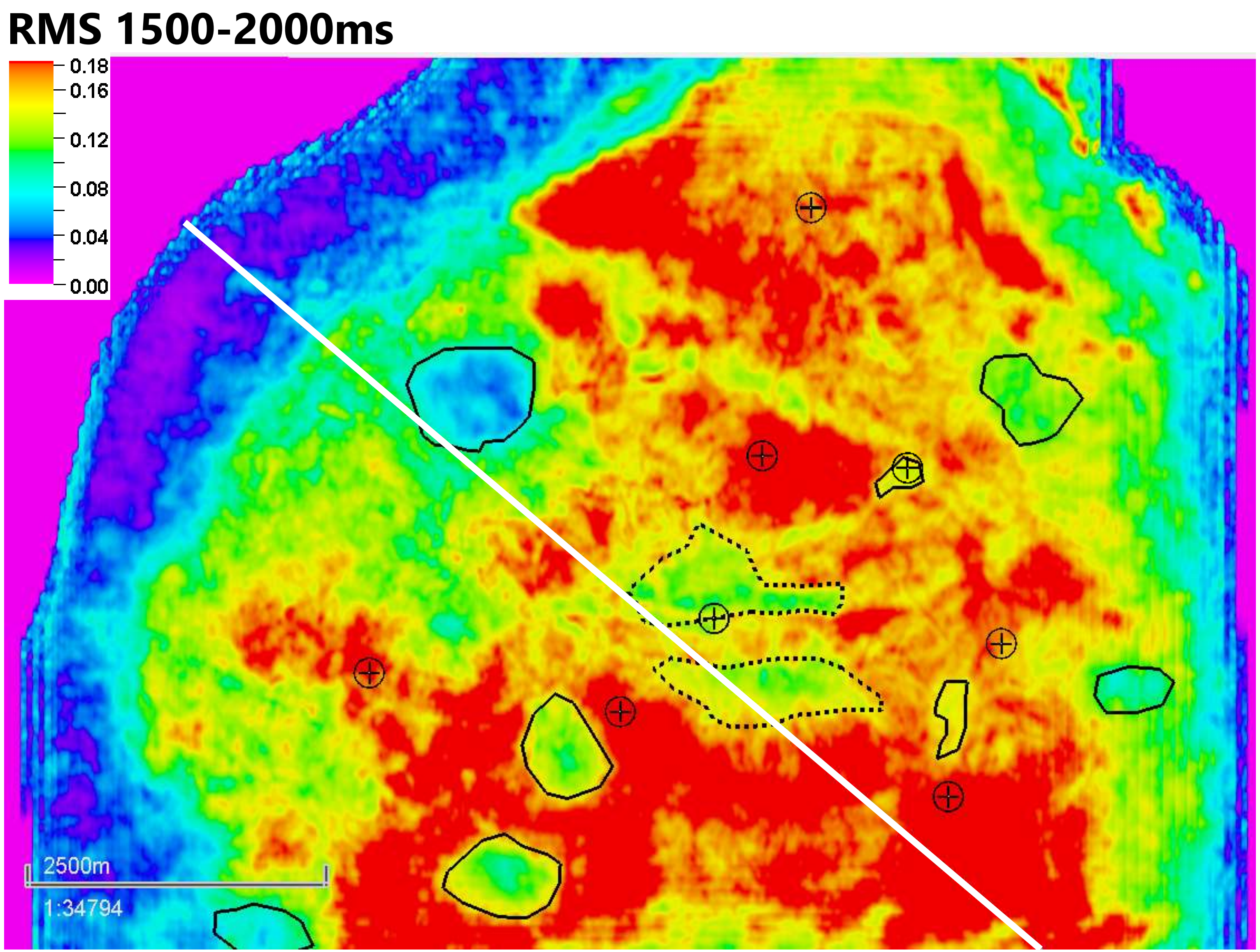
Signal QC: RMS Amplitude Extractions

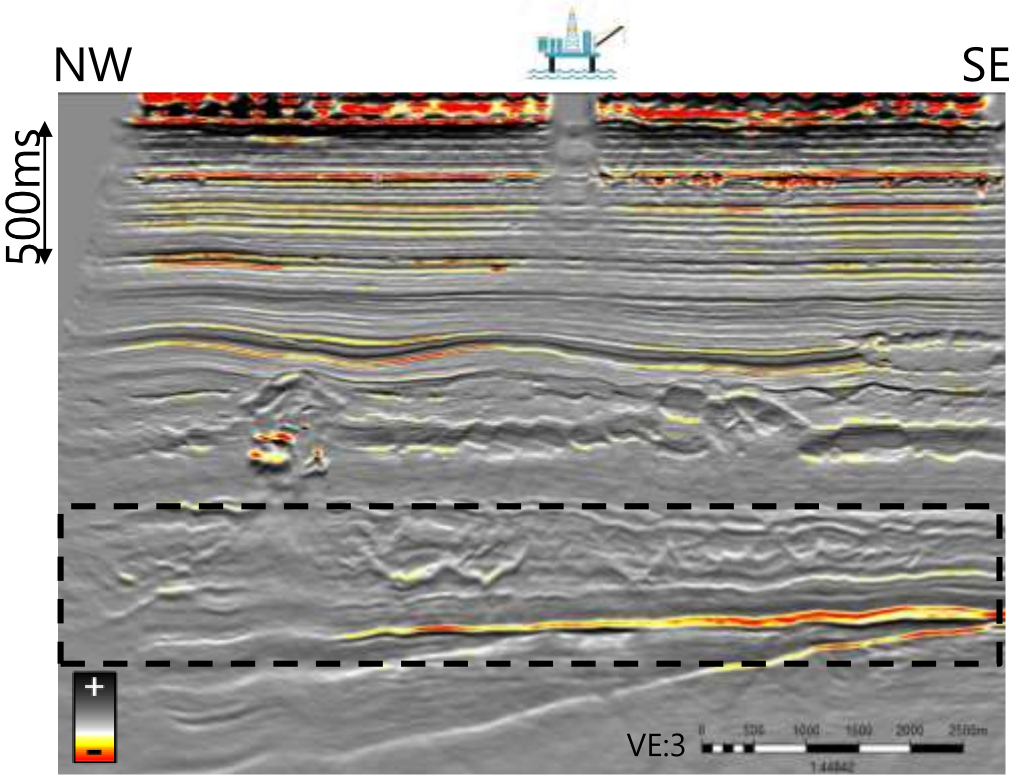
RCP
In pursuit of new ideas



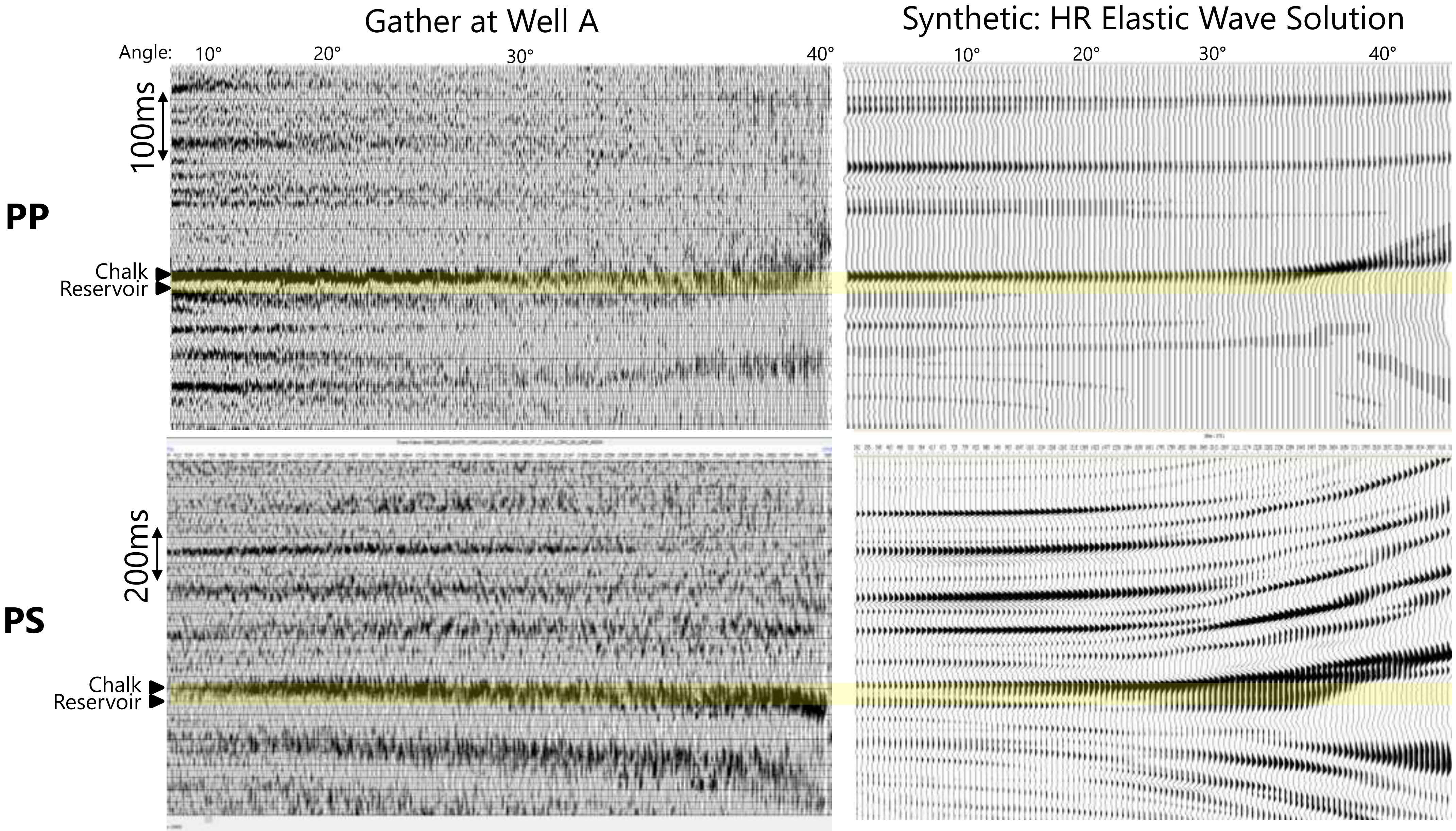


Areas with Signal Loss in Reservoir





AVA QC


Gather at Well A
Synthetic: HR Elastic Wave Solution
Angle:
10°
20°
30°
40°
10°
20°
30°
40°
100ms
200ms
PP
PS
Chalk
Reservoir
Chalk
Reservoir

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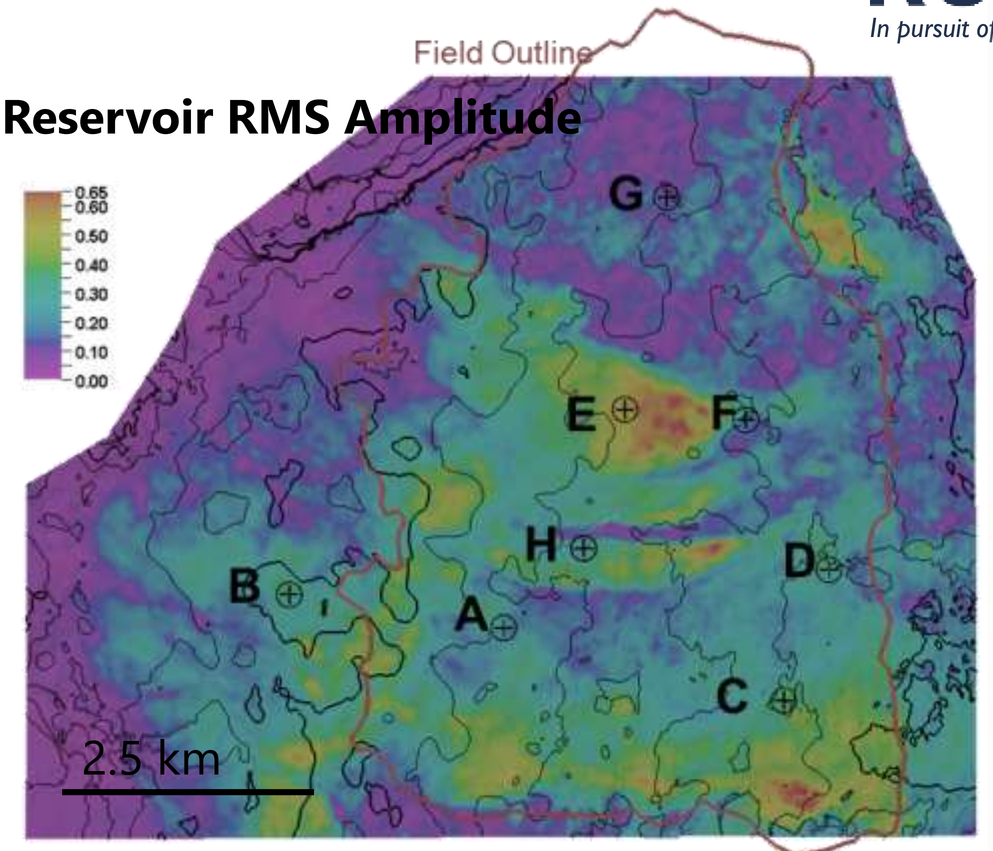

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HRS Strat Inversion Workflow

RCP
In pursuit of new ideas

Well Log Data

Vp, Vs, ρ

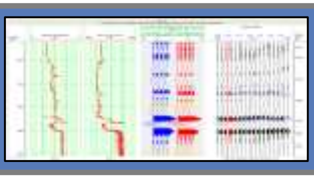
Seismic Data

PostStack: 0-34° stack

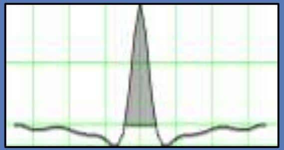
Prestack: 4 Angle Stacks

QC: Synthetic vs. Real Data for AVA, Noise, Transmission Path Issues

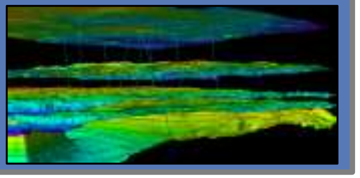
Well Ties



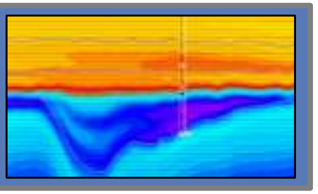
Wavelet Extraction



Horizon Picking



Low-Frequency Initial Model



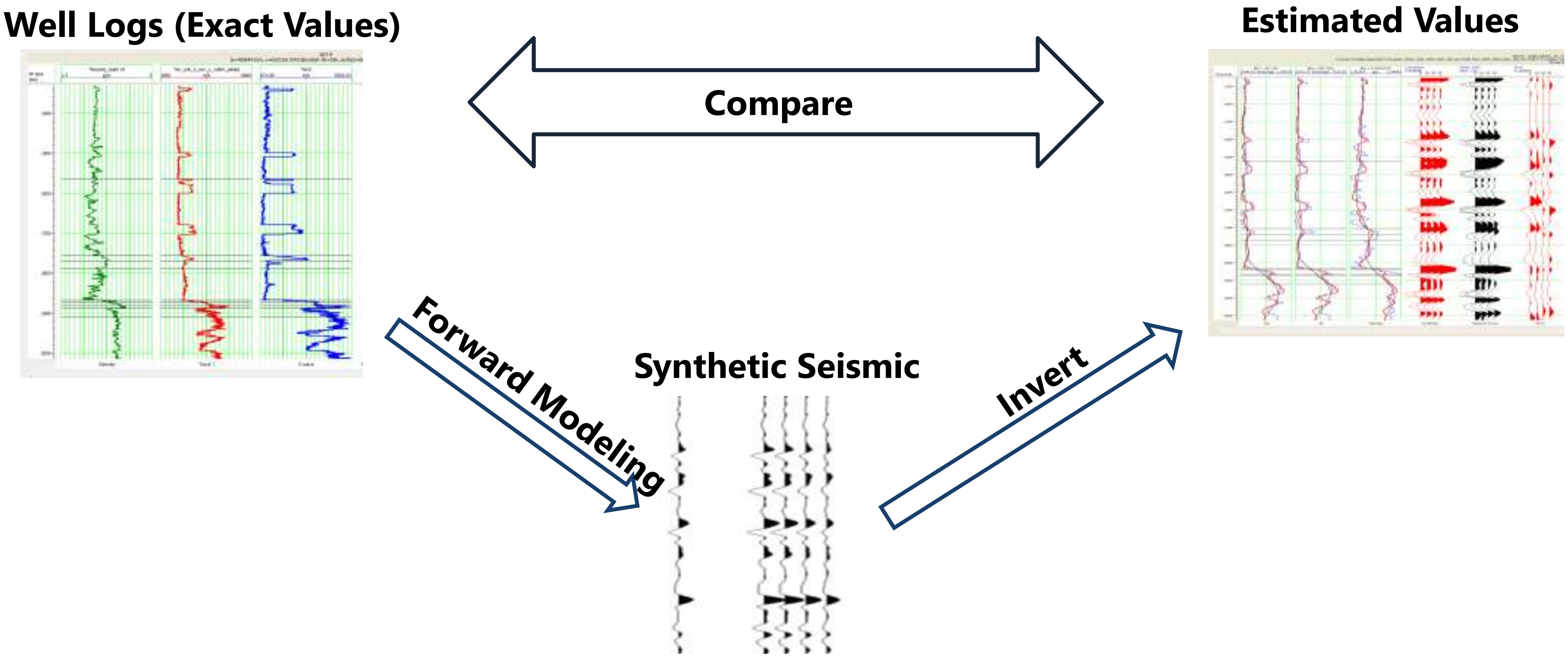
Inversion

Poststack: Zp

Prestack: Zp, Zs, Vp/Vs, ρ

Synthetic Post Stack Inversion

- “Best Case Scenario” for Post-Stack Inversion Result
  - 1D Smoothed Initial Model



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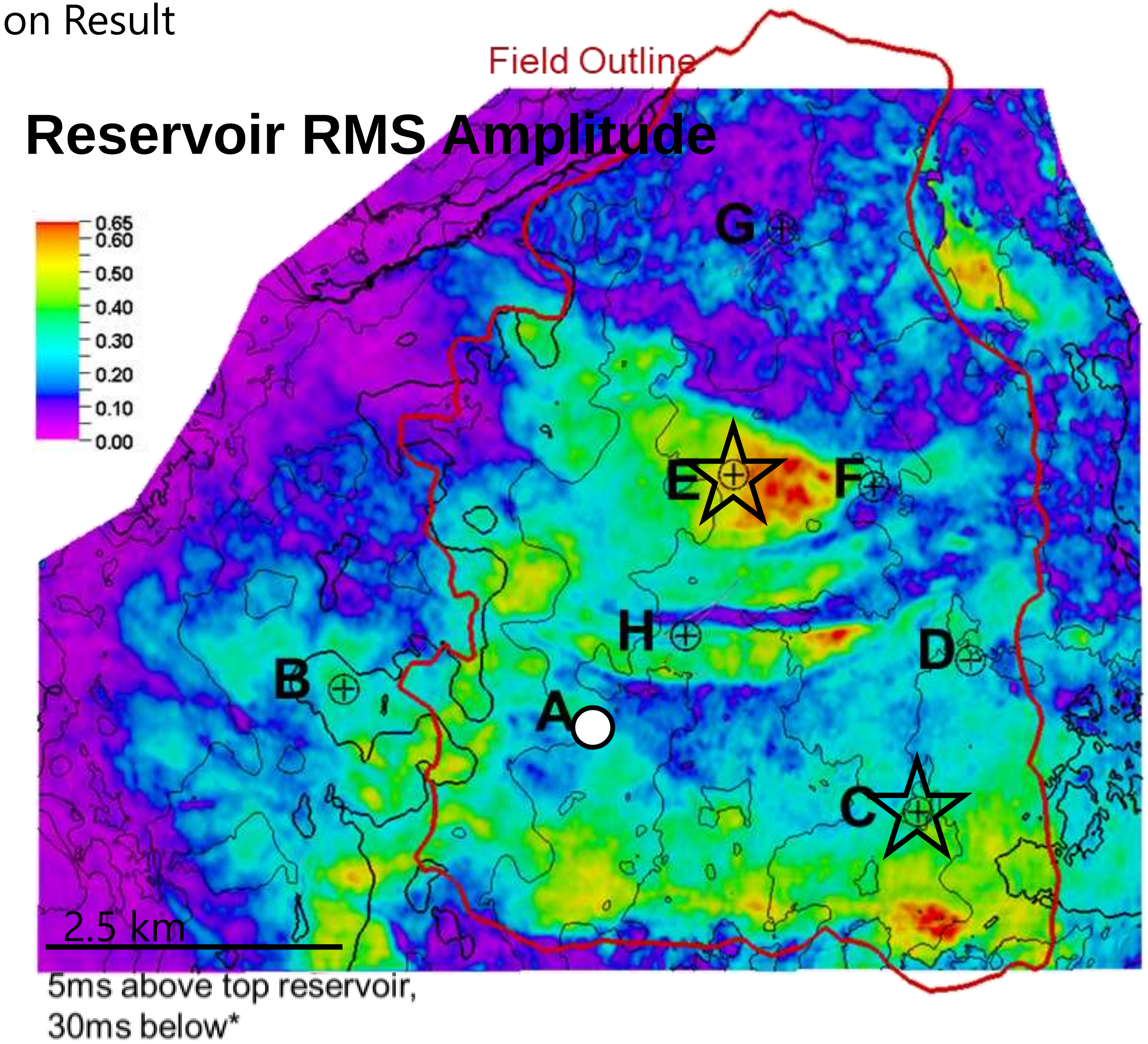

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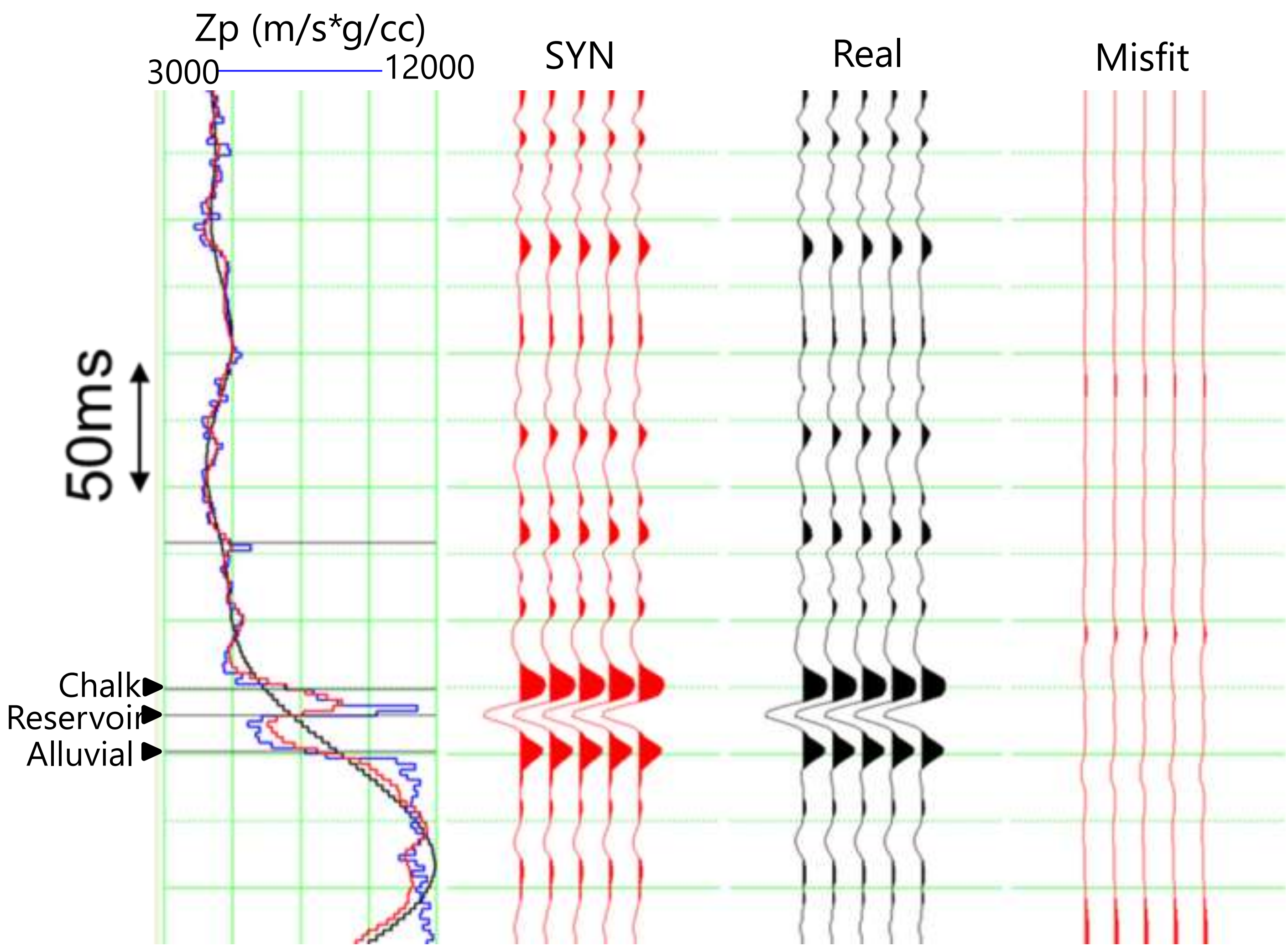
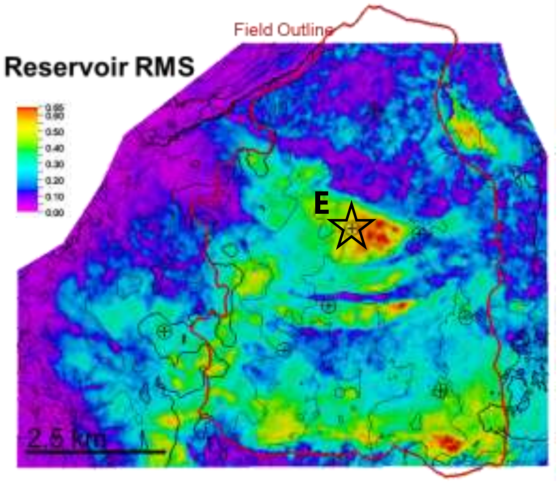
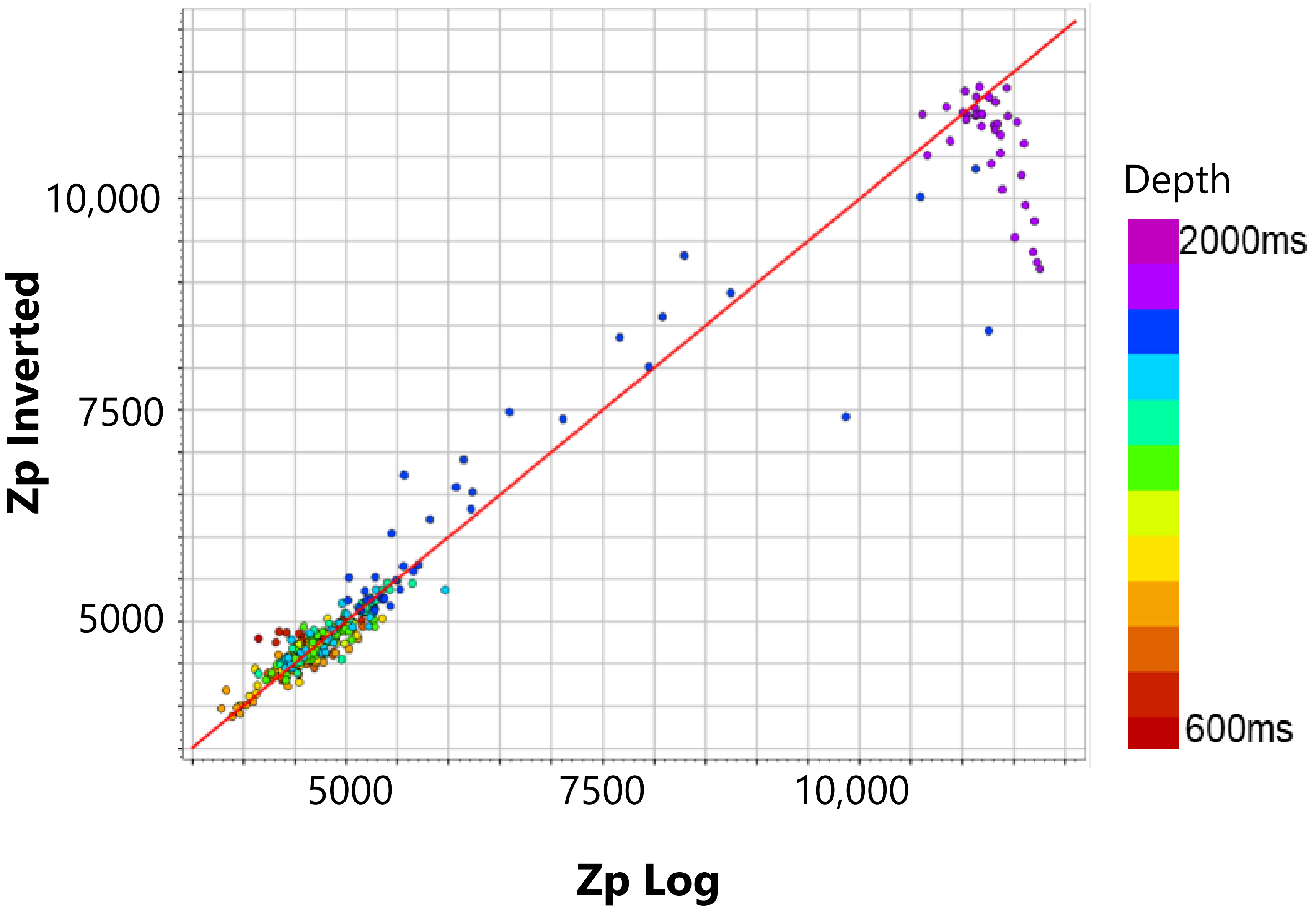


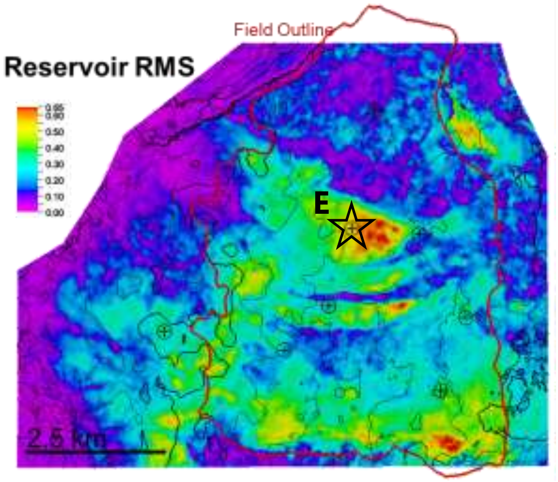


Zp Legend:
Well Data
Initial Model
Inversion Result
Map Legend:
Initial Model Wells
Wells Shown

Synthetic Post Stack Inversion

RCP
In pursuit of new ideas





Zp Legend:
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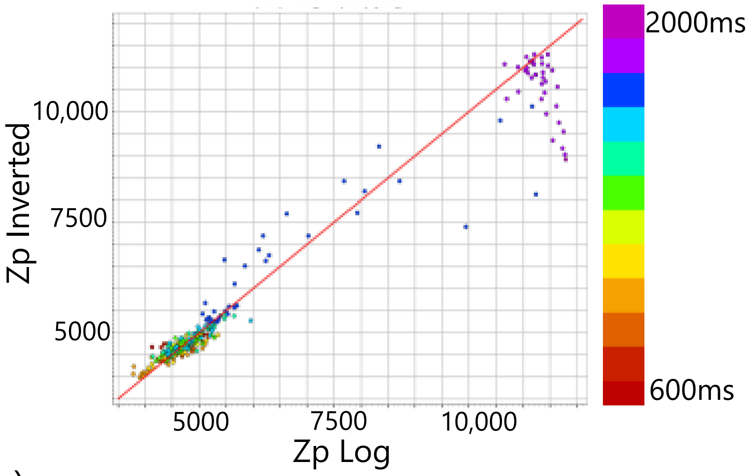
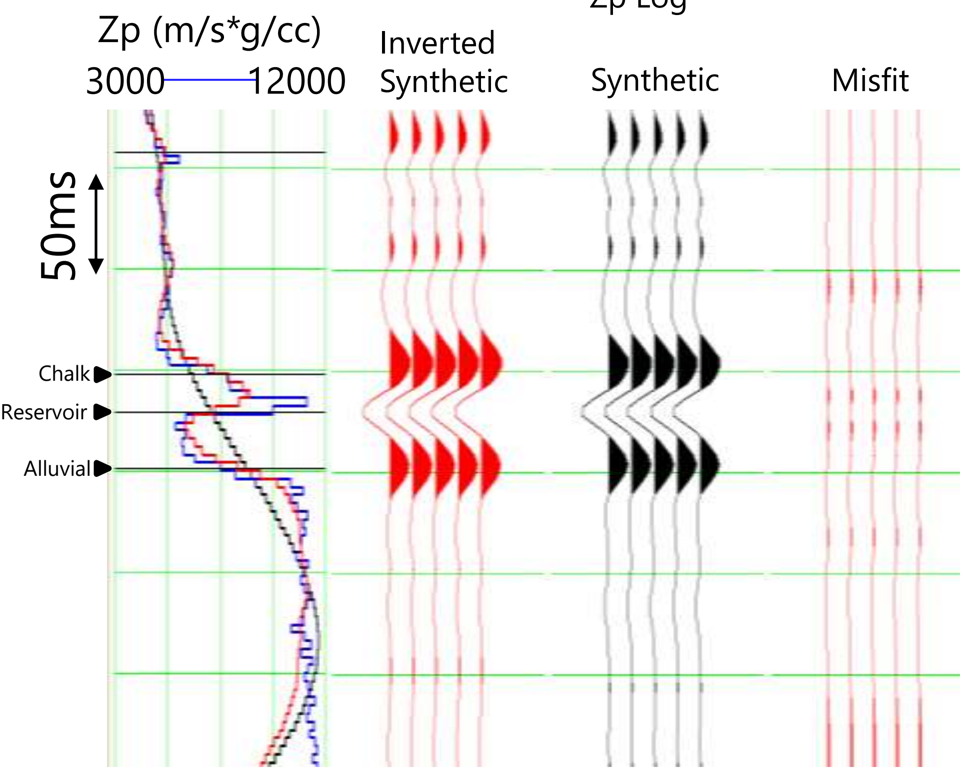
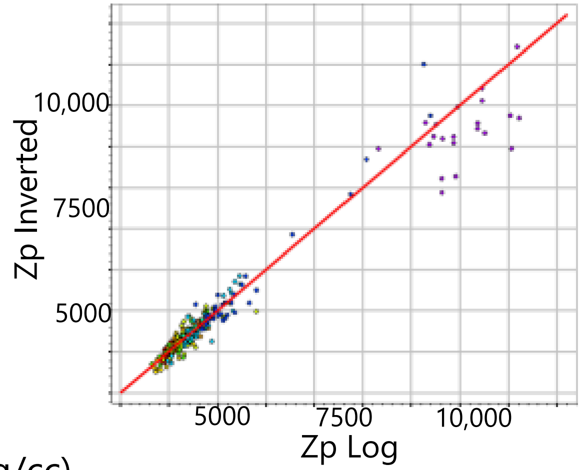
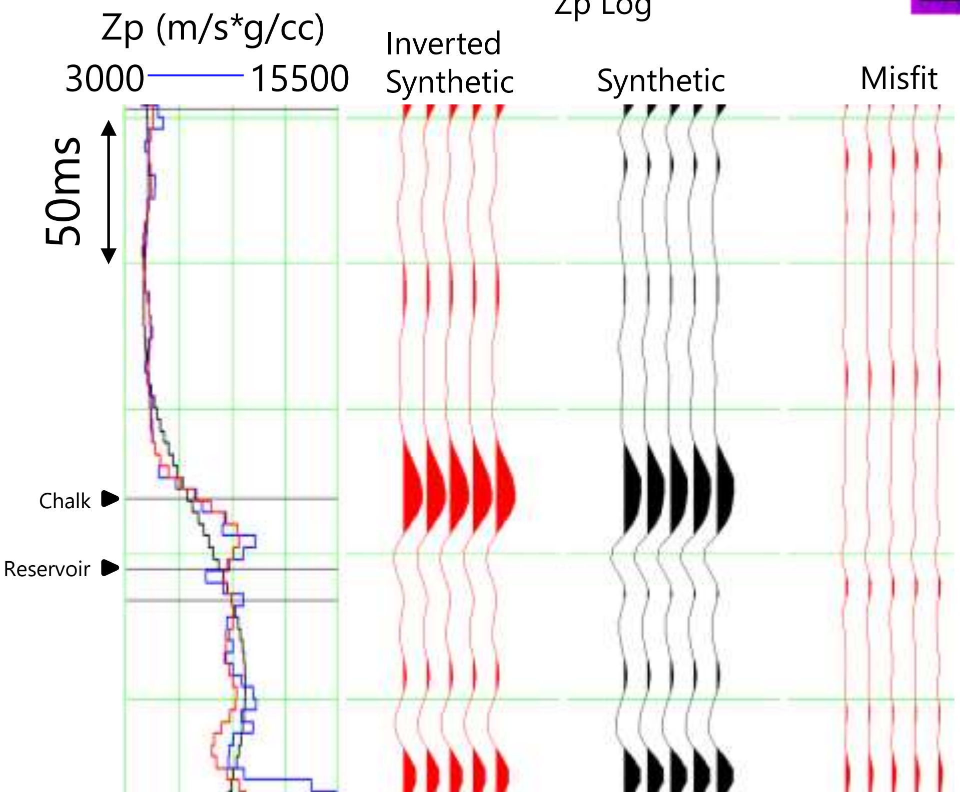


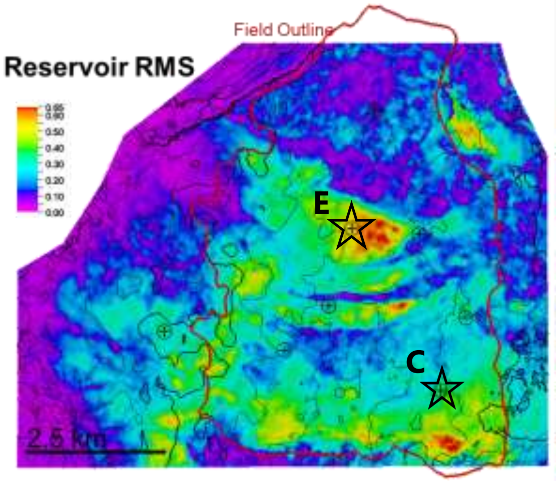
Well E





Well C





Zp Legend:

Well Data

Initial Model

Inversion Result

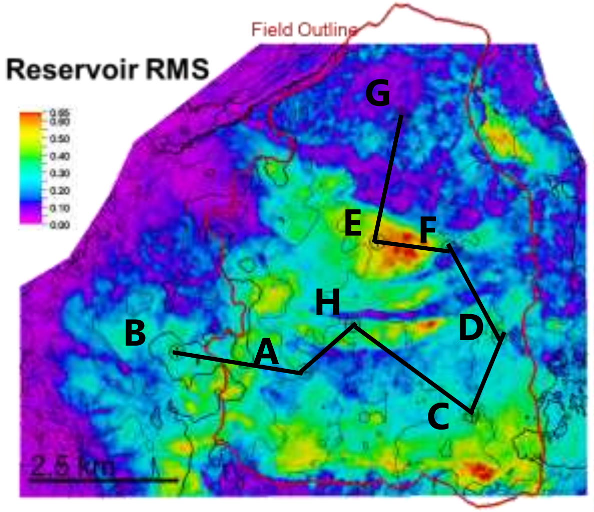
Map Legend:

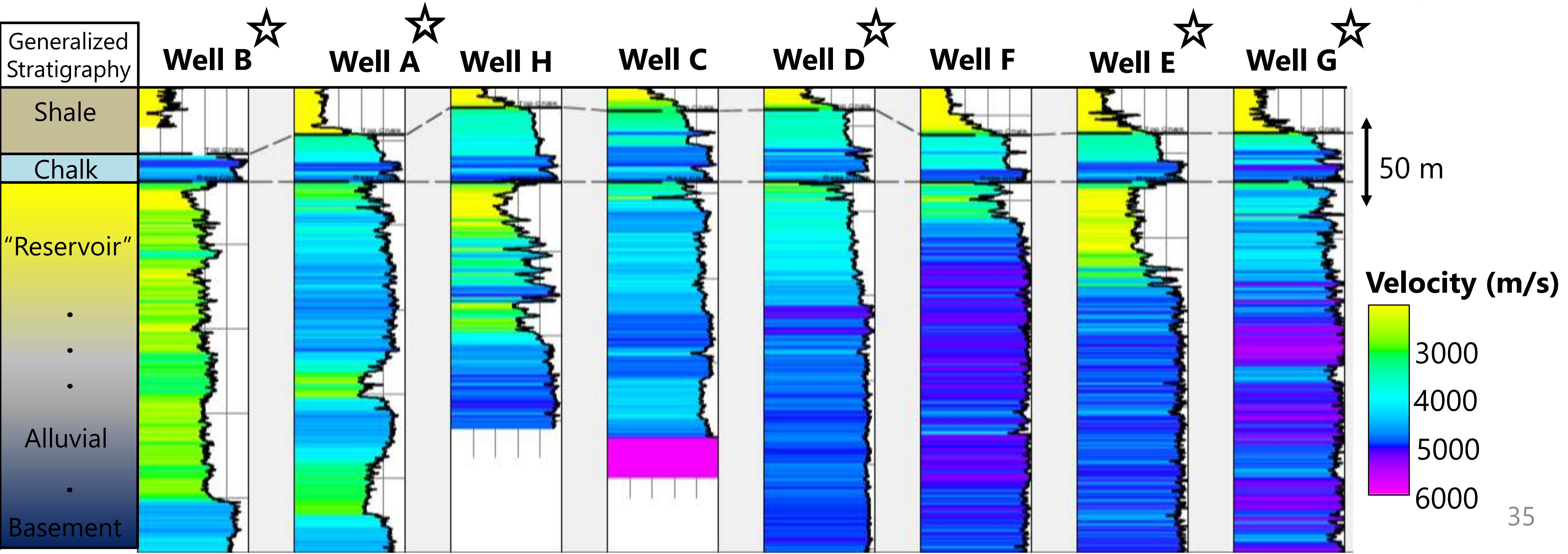
Initial Model Wells

Wells Shown

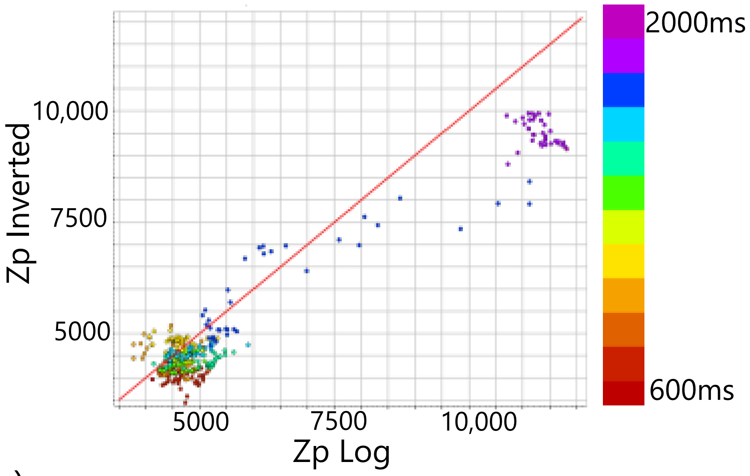
Potential Wells for Low Frequency Model

- Inputs to the LFBM should adequately sample spatial facies change

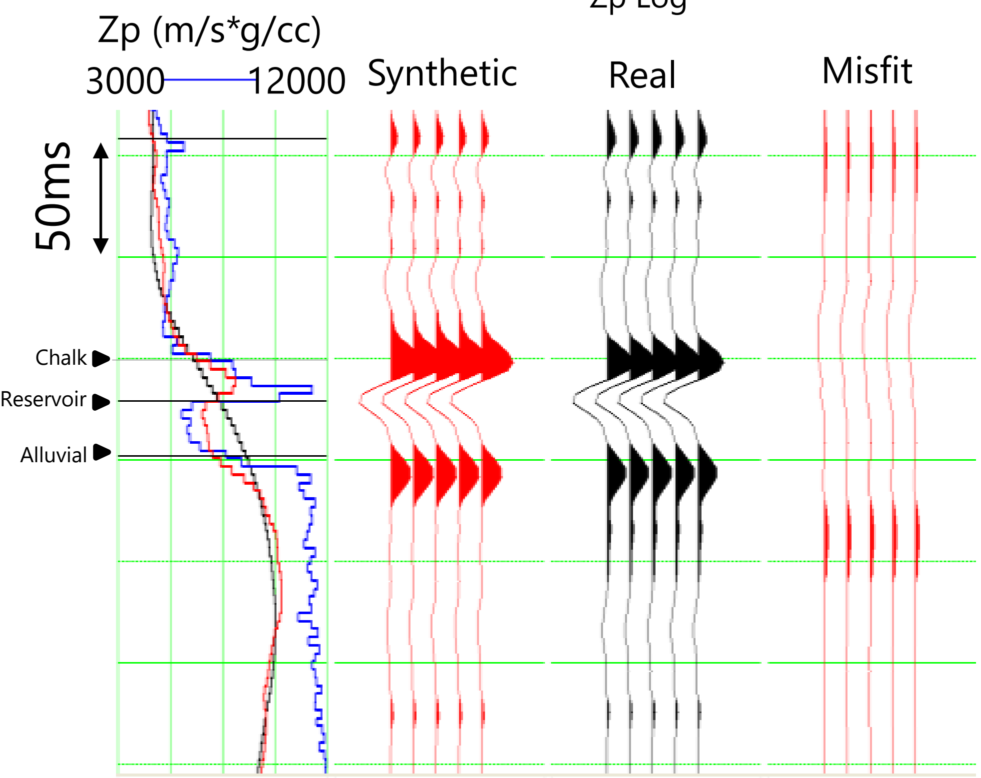


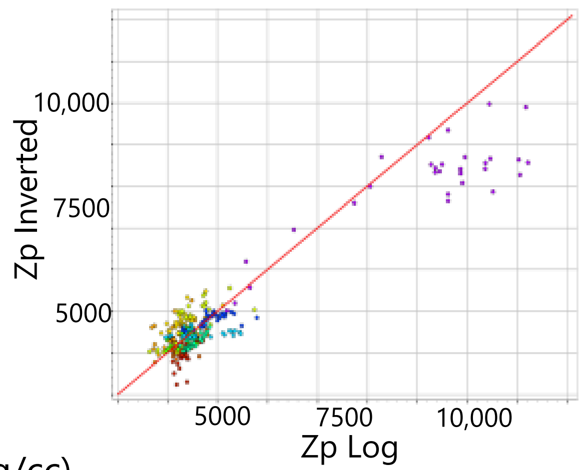


Post-Stack Inversion Real Data: 1 Well

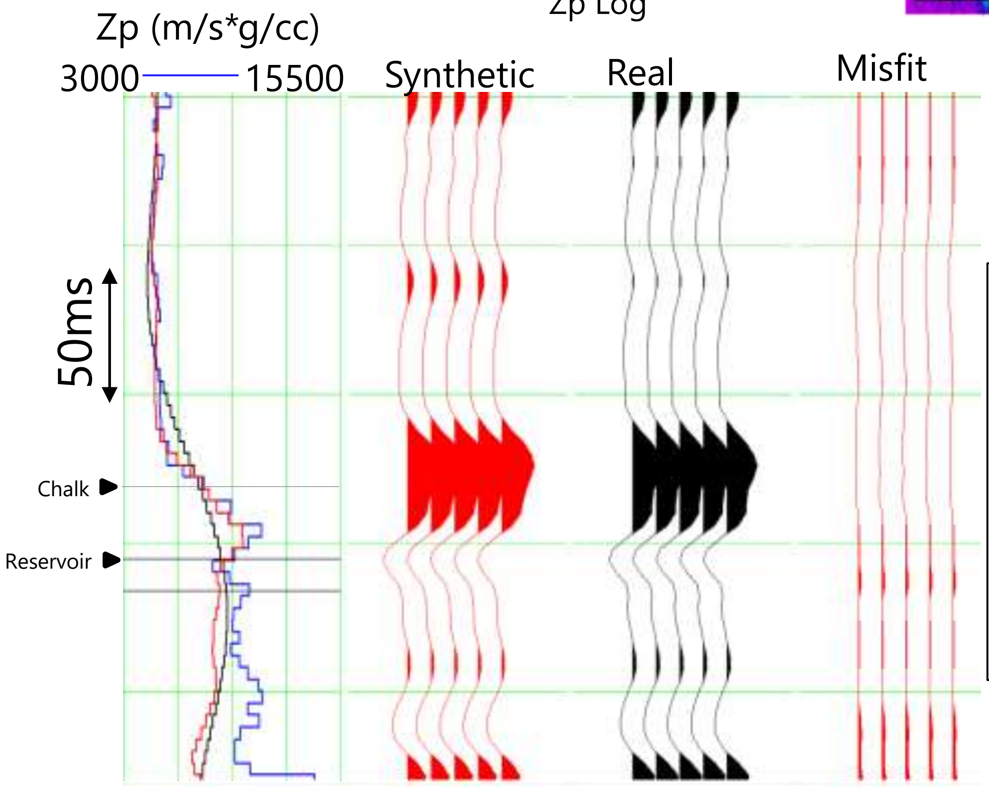


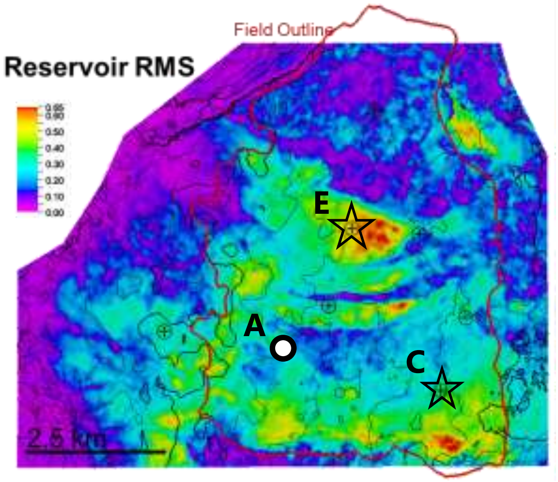
Well E





Well C





Zp Legend:
- Well Data
- Initial Model
- Inversion Result

Map Legend:
- Initial Model Wells ○
- Wells Shown ☆

Post-Stack Inversion Real Data: 5 Wells

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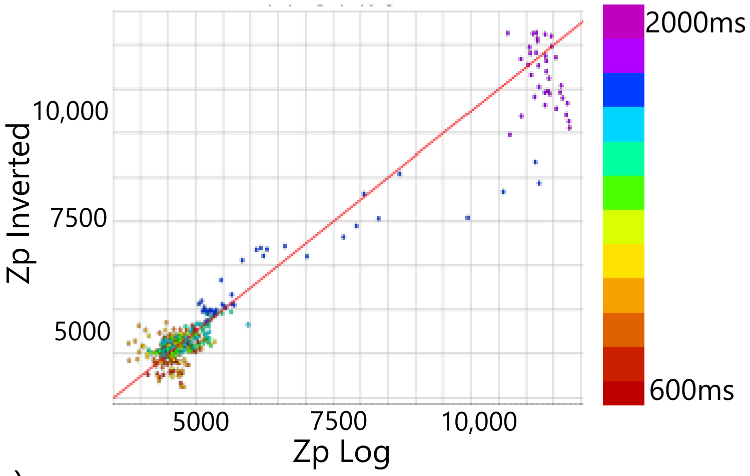
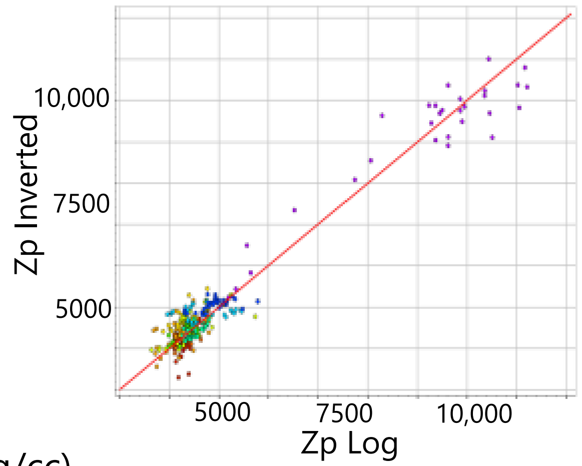
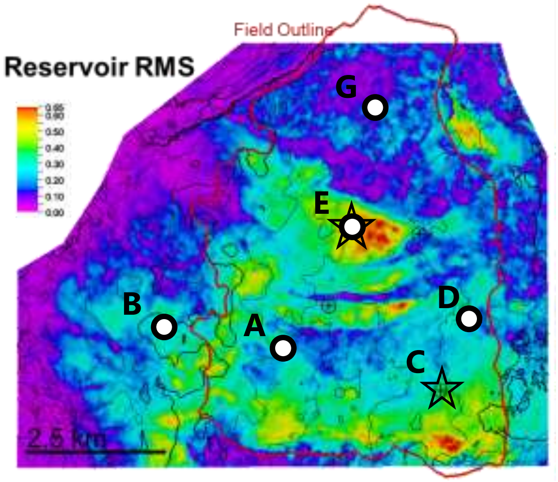
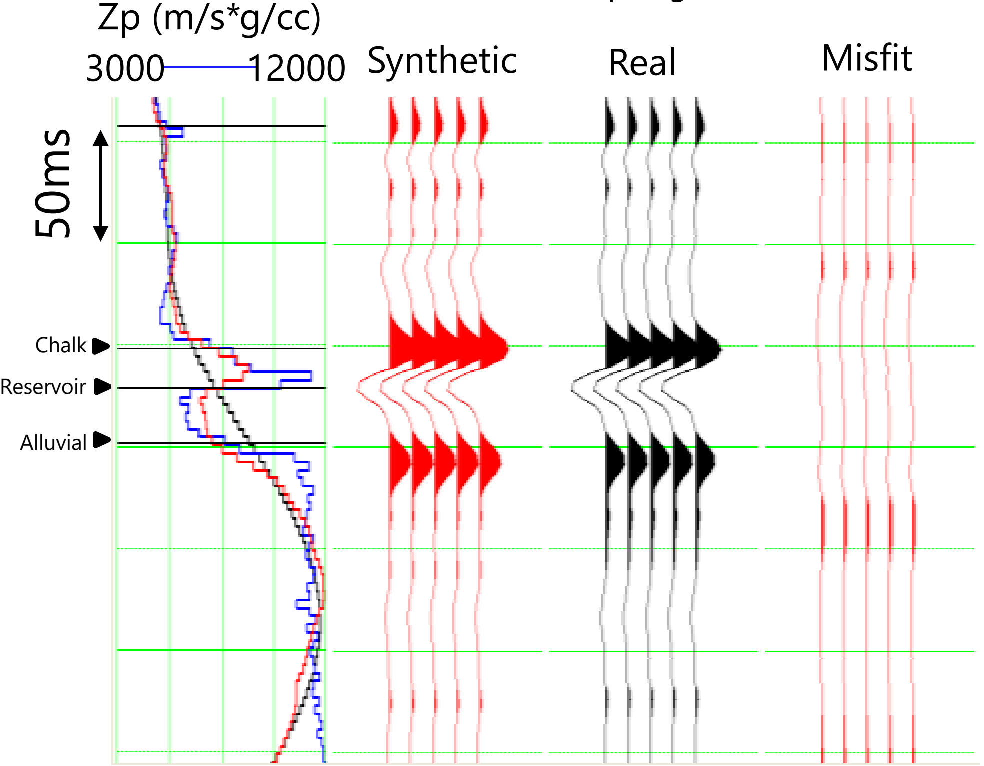


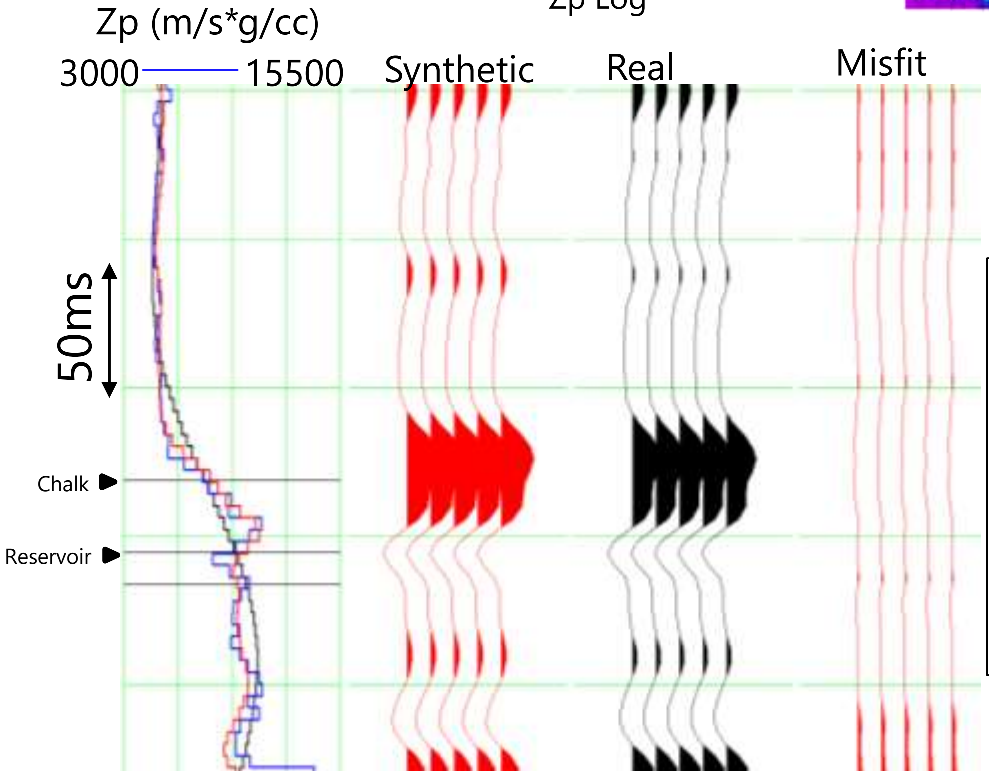




Well E



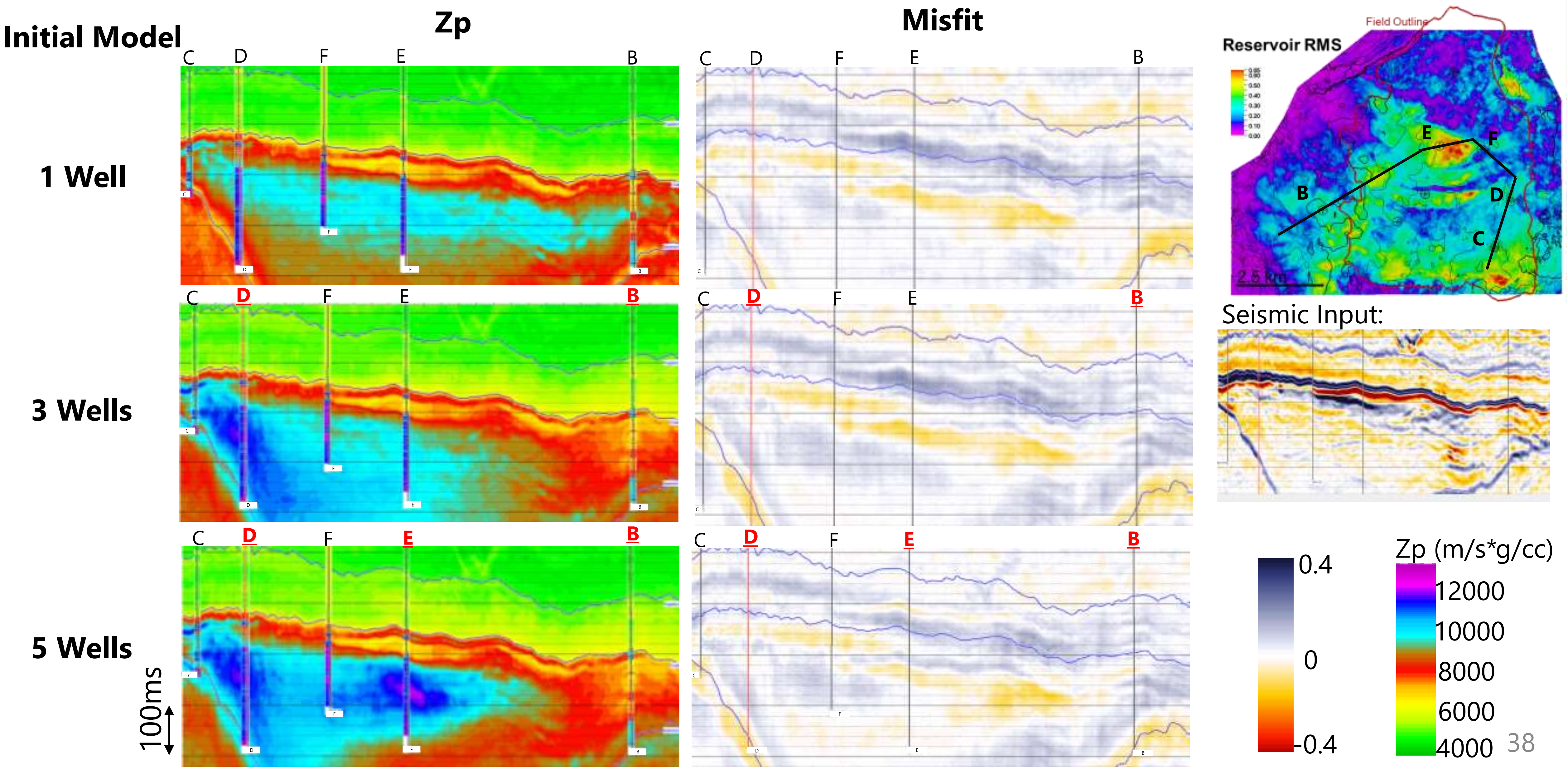
Well C



Zp Legend:
- Well Data
- Initial Model
- Inversion Result

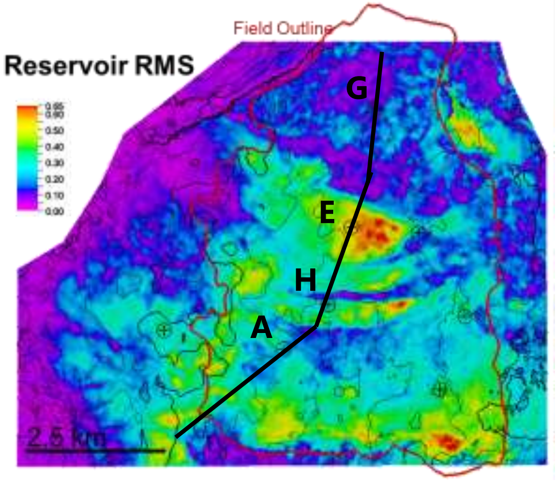
Map Legend:
- Initial Model Wells ○
- Wells Shown ☆

Post-Stack Inversion Results

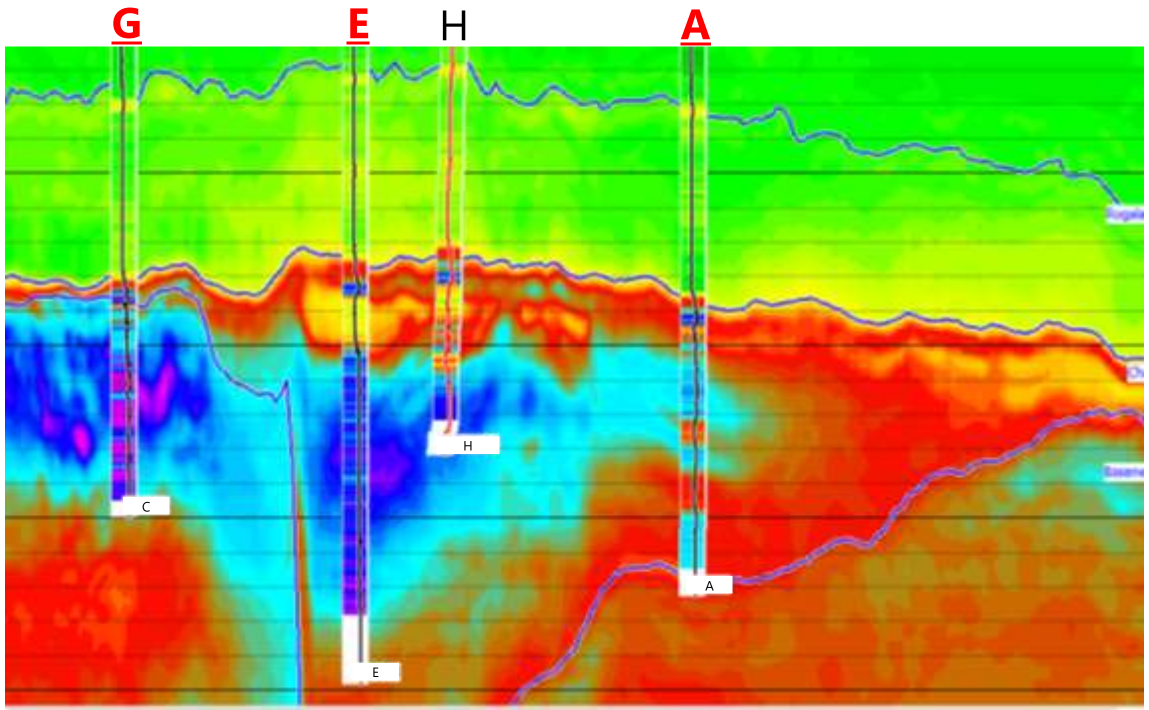


“Best” Post-Stack Inversion Result

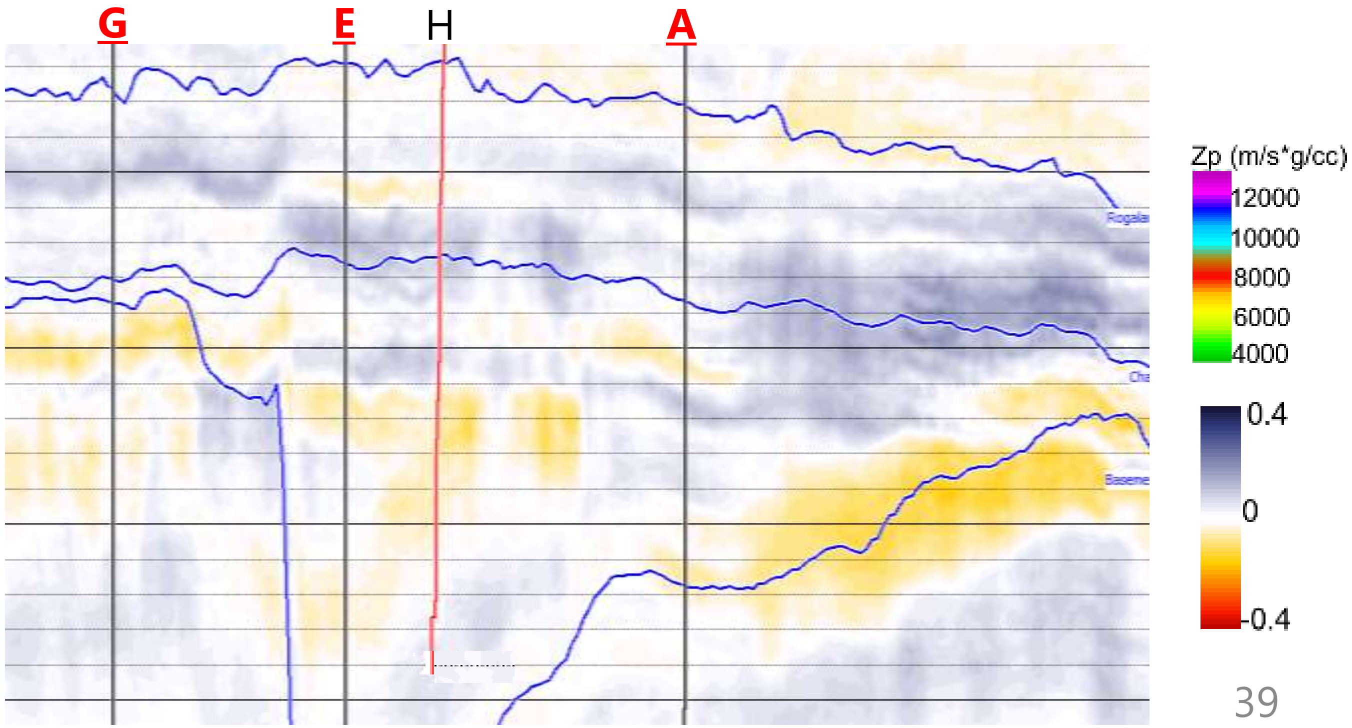
- 5 Variable Facies Wells for Initial Low Frequency Model
  - Lowest misfit in reservoir unit
  - Characterizes base and top reservoir
- For laterally variable geology, sufficient representative wells should be included in the LFBM to adequately sample heterogeneity



Zp



Misfit



HRS Strat Inversion Workflow: Prestack PP

Well Log Data

Vp, Vs, ρ

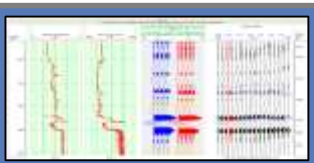
Seismic Data

PostStack: 0-34° stack

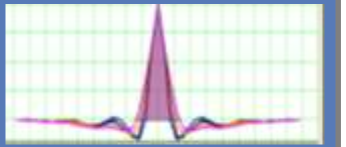
Prestack: 4 Angle Stacks

QC: Synthetic vs. Real Data for AVA, Noise, Transmission Path Issues

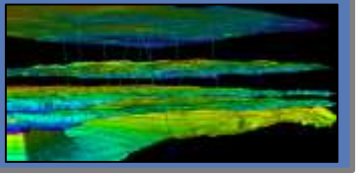
Well Ties



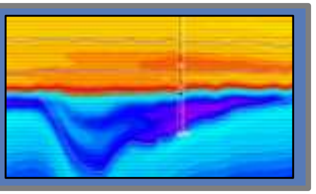
Wavelet Extraction



Horizon Picking



Low-Frequency Initial Model

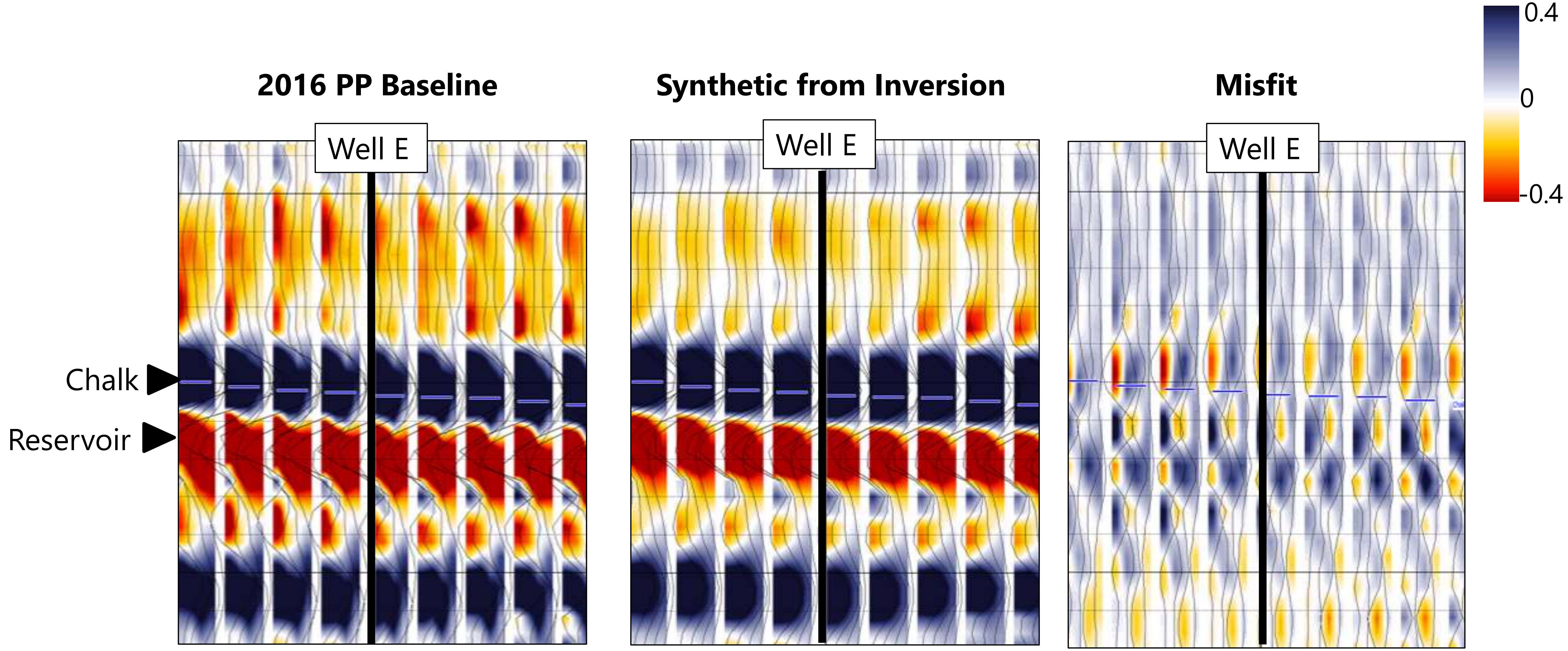


Inversion

Poststack: Zp

Prestack: Zp, Zs, Vp/Vs, ρ

Prestack Inversion Residual Moveout



Post-Stack vs. Pre-Stack Inversion: 5 Wells LFM

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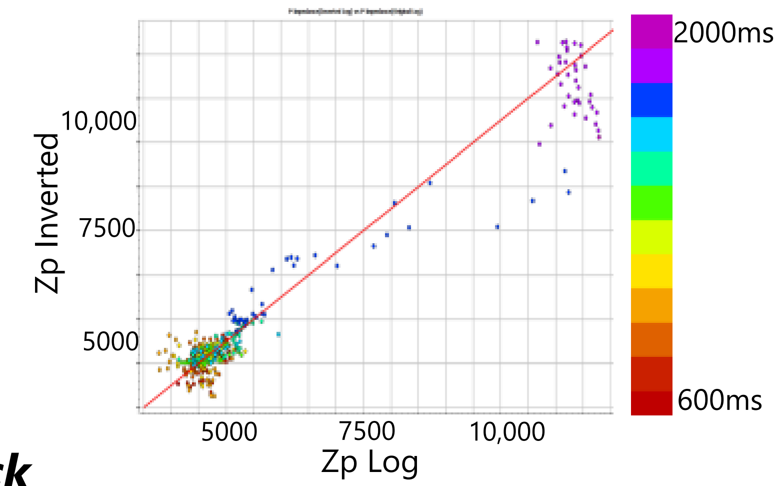
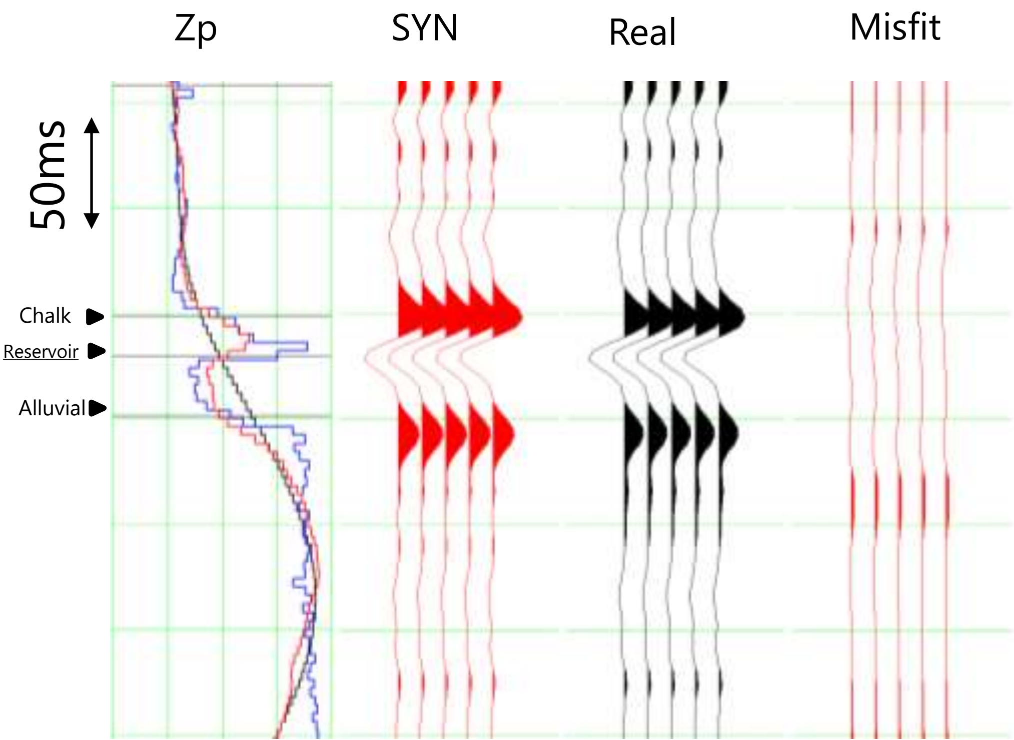
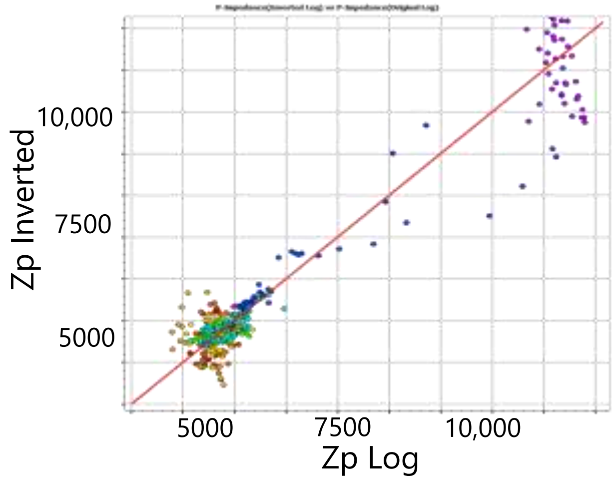
Well E

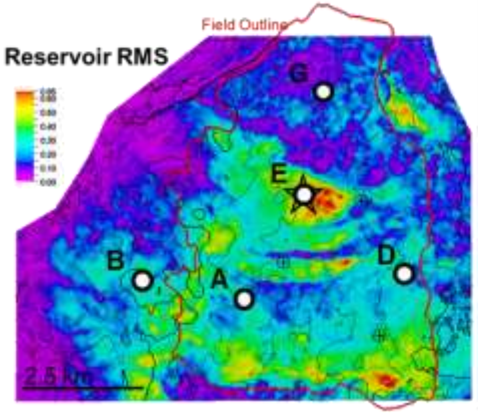


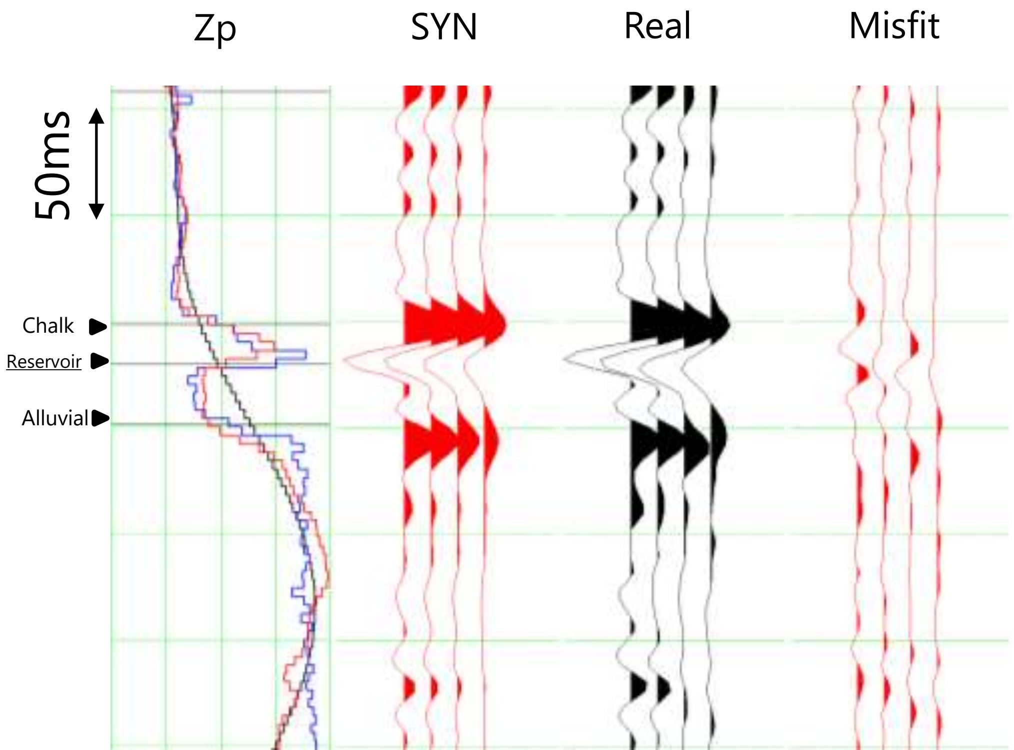
Poststack



Prestack







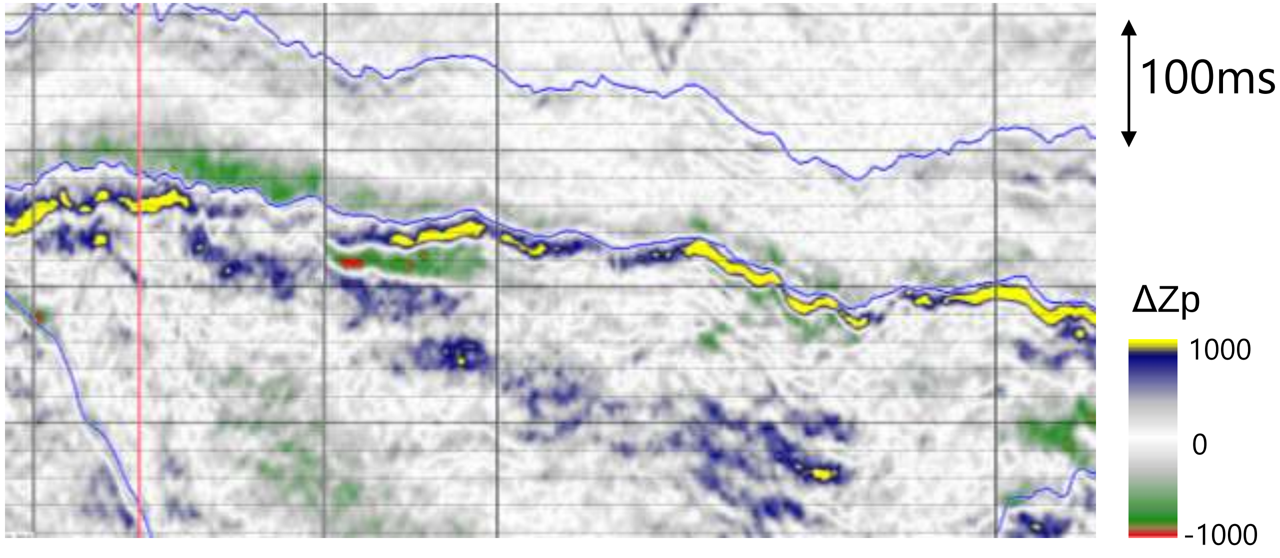
Zp Legend:
- Well Data (blue line)
- Initial Model (black line)
- Inversion Result (red line)

Map Legend:
- Initial Model Wells: ○
- Wells Shown: ☆

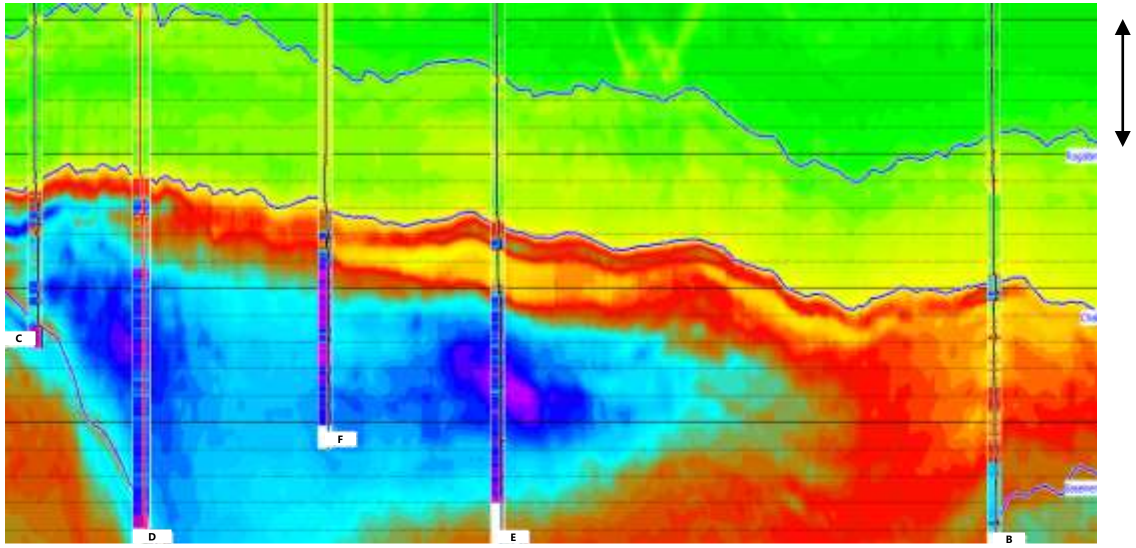
Initial PP Inversion Observation

- Pre-Stack PP inversion is able to capture sharper impedance changes
- Pre-Stack data contains more noise, residual move out, needs conditioning to improve results

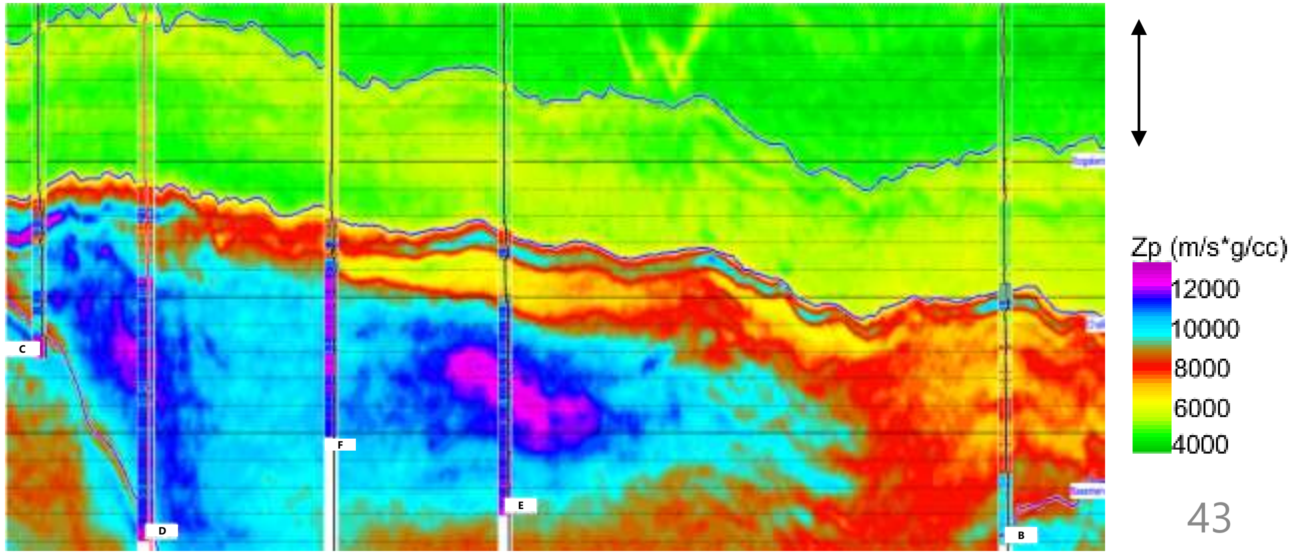
Prestack Zp – Poststack Zp



Poststack Zp



Prestack Zp



Conclusion

- Changes in S-Impedance can help characterize variable reservoir facies and the reservoir response to development in Edvard Grieg

- Fields that vary facies laterally require multiple representative well logs for the initial model input to sample heterogeneity
  - 5 well logs produces best PP inversion result for Edvard Grieg

- Pre-Stack PP inversion better characterizes low impedance reservoir and overlying chalk

Future

- Gather conditioning to remove residual moveout
- Further QC of inversion results
- PS Inversion and Registration
- Joint 4D PP/PS inversion to ultimately evaluate PS data benefits in characterizing heterogeneity and development effects

Thank you

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Per Eivind Dhelie, Lundin Norway AS
Emilie Davenne, Lundin Norway AS

The partners in PL338 Edvard Grieg, OMV and Wintershall

AFL
Anadarko Petroleum Corporation
Apache
CGG
Chevron
CIMAREX
CNOOC
DAWSON Dawson Geophysical Company
devon
drillinginfo better, faster decisions
eog resources
ExxonMobil
Great Western OIL & GAS COMPANY
HALLIBURTON Landmark
HighPoint RESOURCES
شركة نفط الكويت Kuwait Oil Company
ikon Science
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Lundin Petroleum
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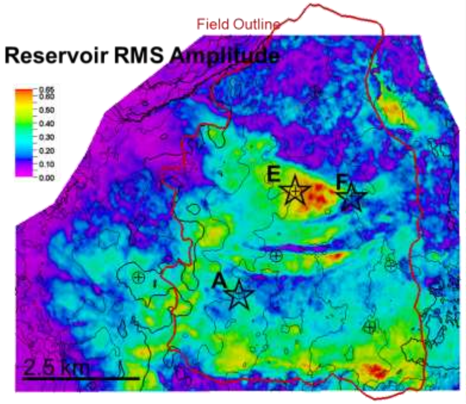
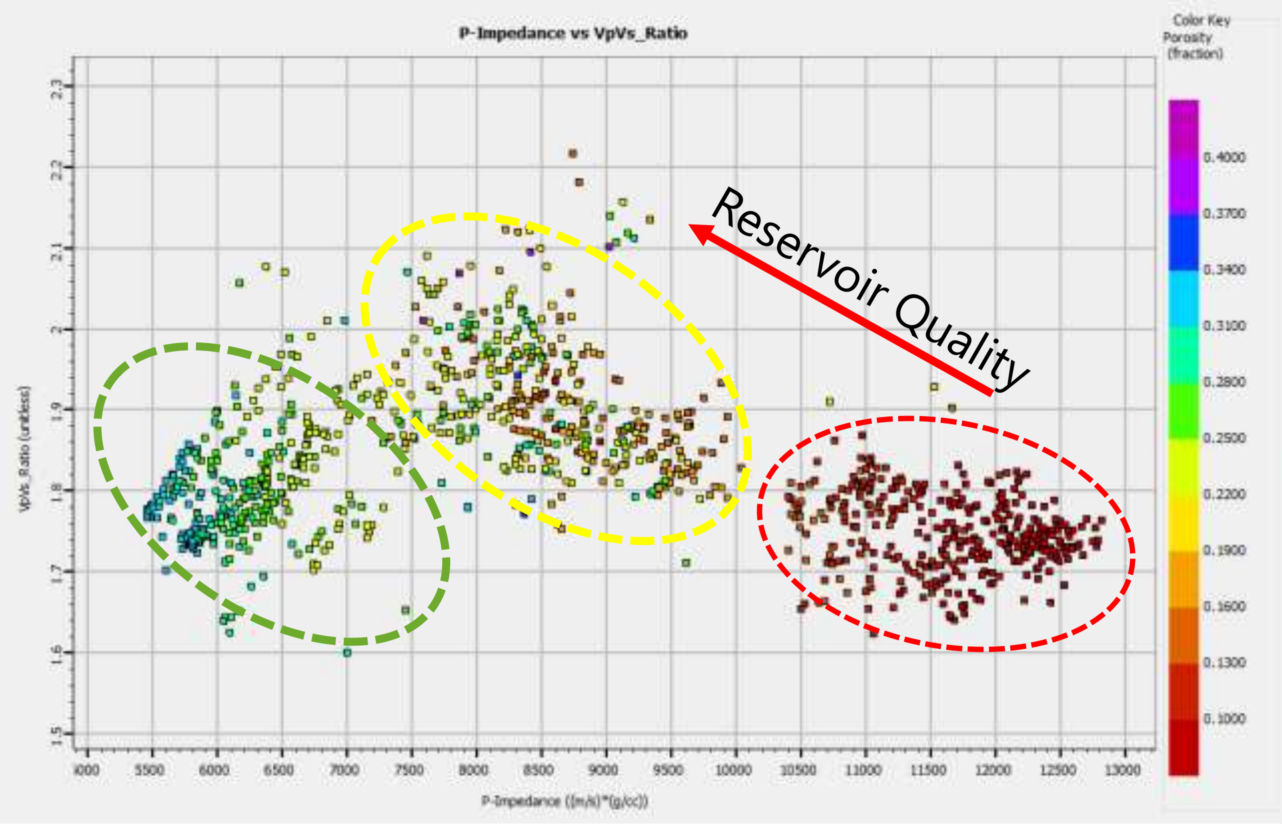
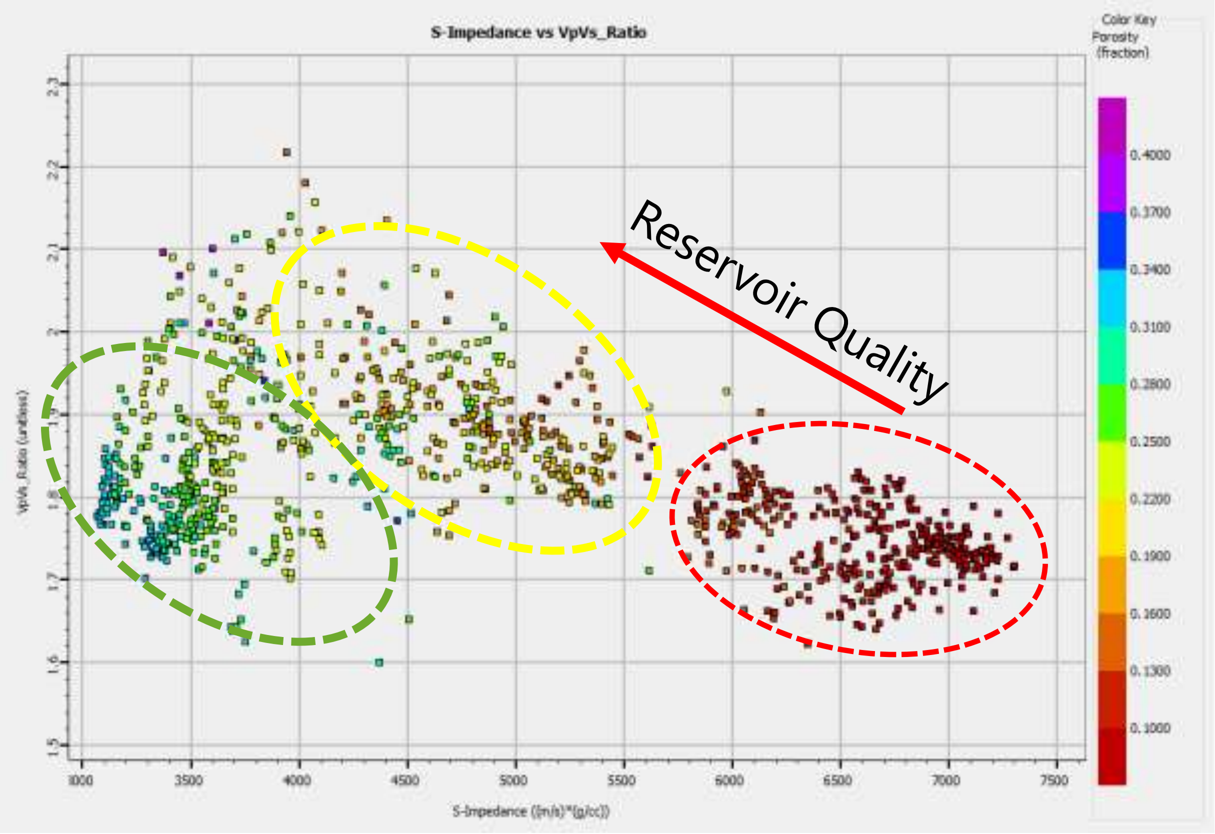
BACKUP

Vp/Vs vs. Impedance

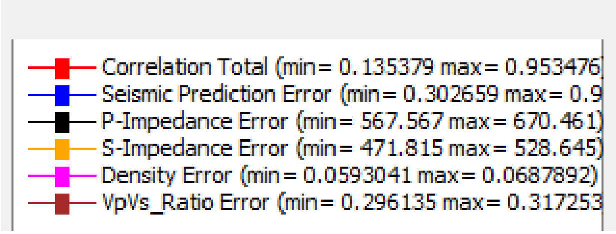


- Vp/Vs correlates with conglomerate porosity
- Both P-Impedance and S-Impedance help distinguish reservoir quality

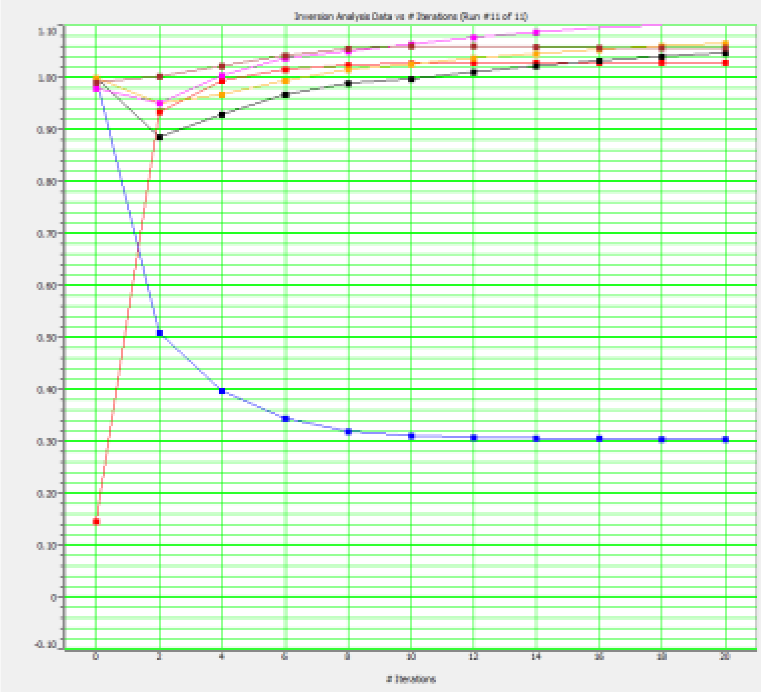




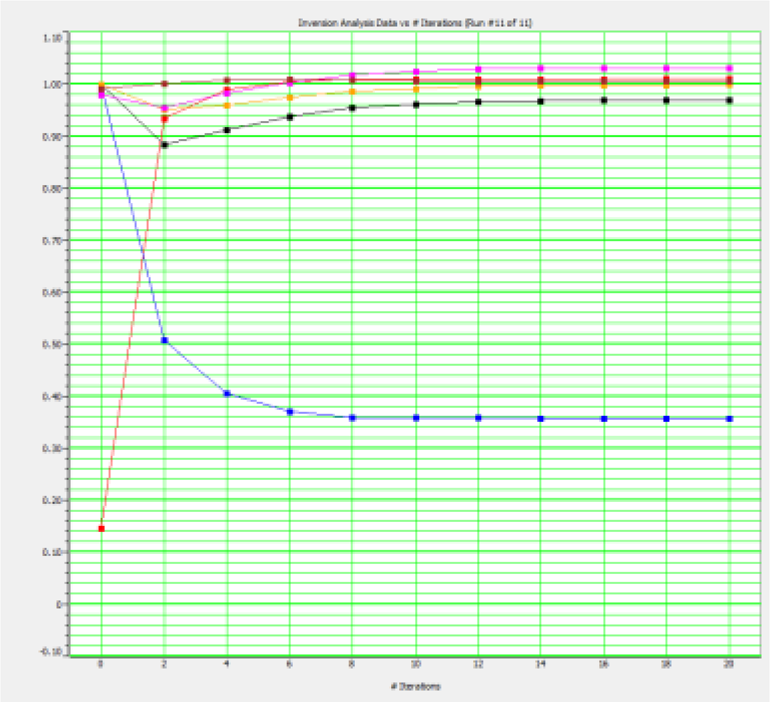
Prestack Controlling Parameters: Prewhitening



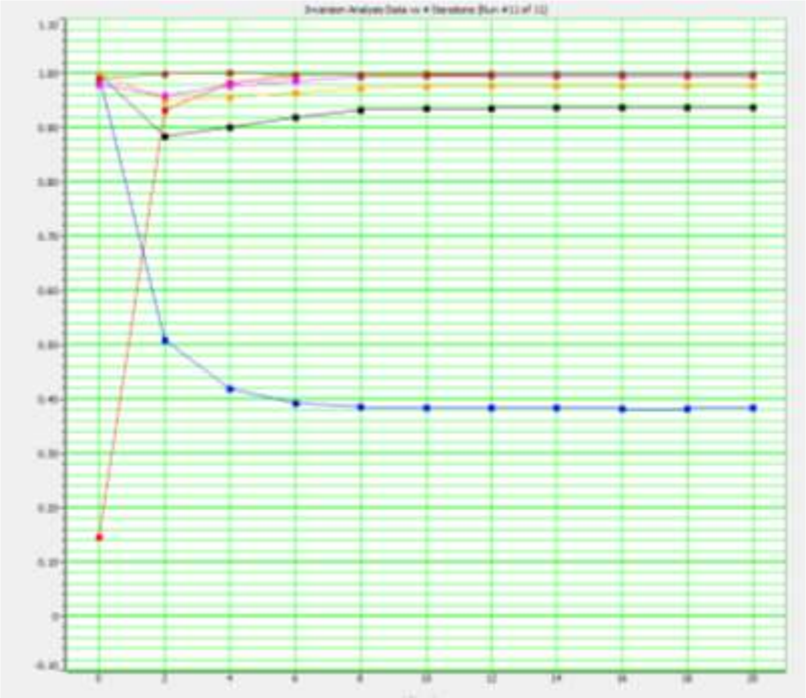
Prewhitening = 1



Prewhitening = 3



Prewhitening = 5



Varying Initial Models:Prestack

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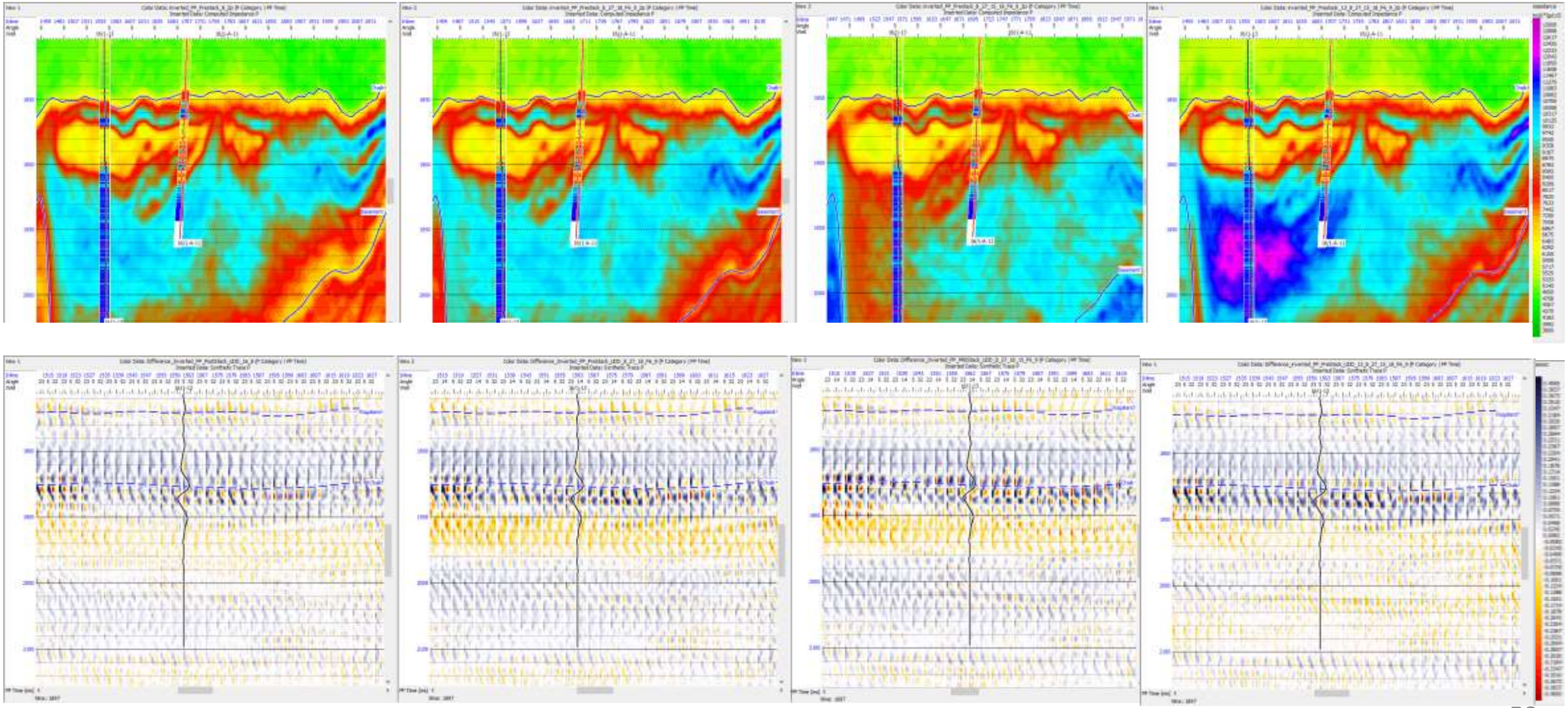
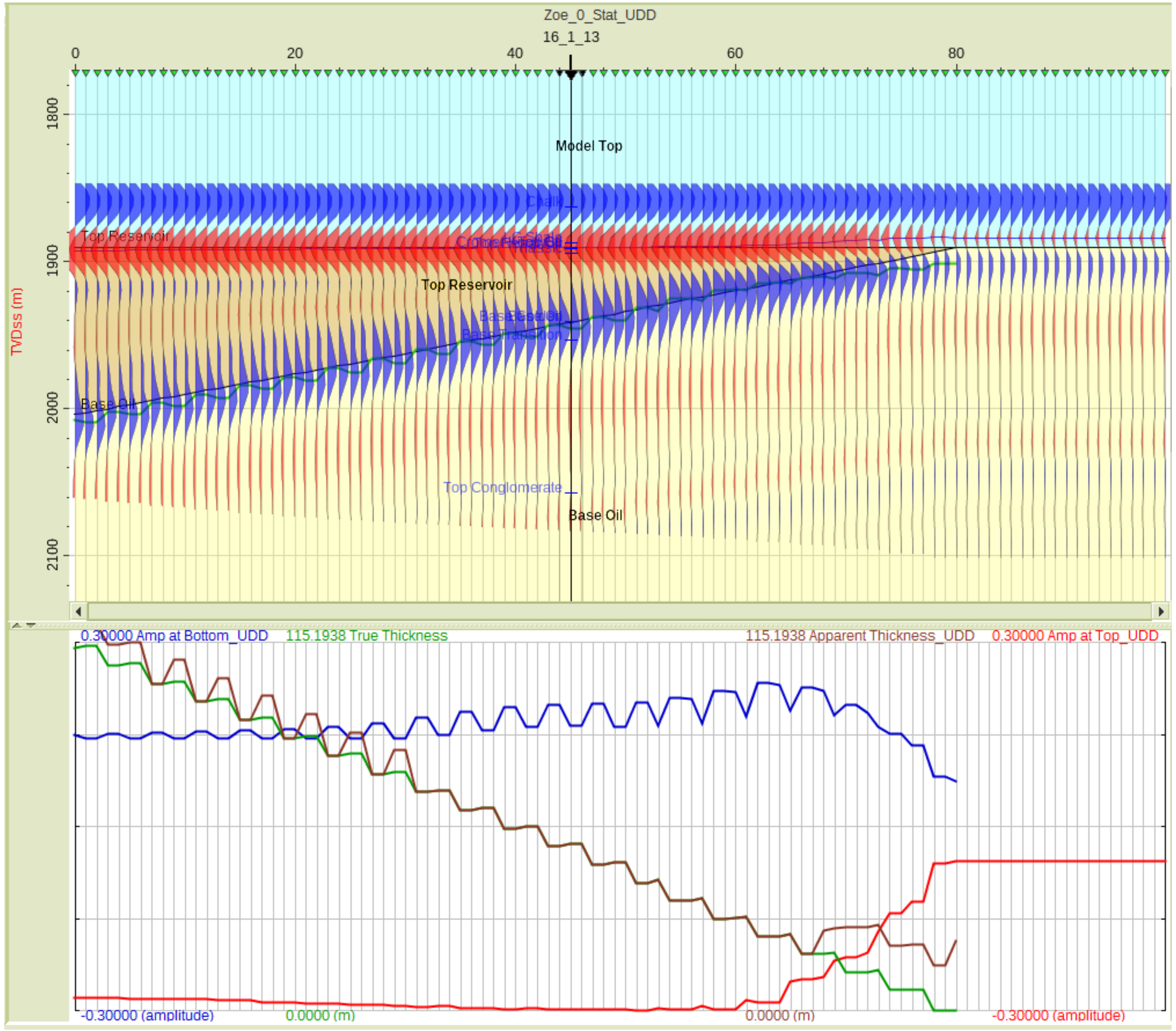
	1 Well Initial Model	3 Well Initial Model	4 Well Initial Model	5 Well Initial Model
Zp				
Misfit				

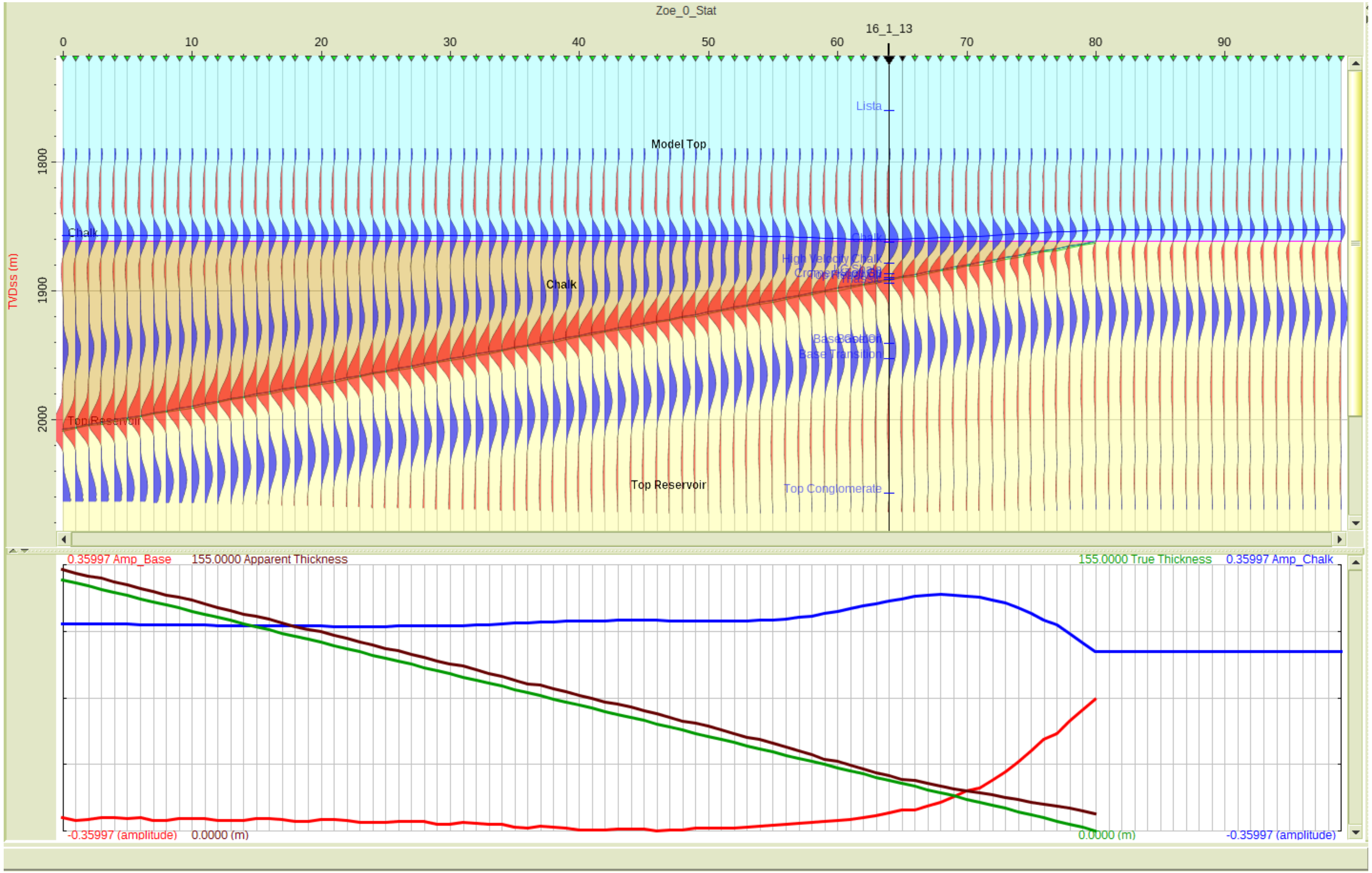


Reservoir Wedge Model: 17m Resolution

Using statistical on UDD data
1500-2000ms window



Chalk Wedge Model: 22m Peak Tuning



Wedge Model: 22m Peak Tuning, Begins Tuning at 50m from interfering internal carbonate units in chalk

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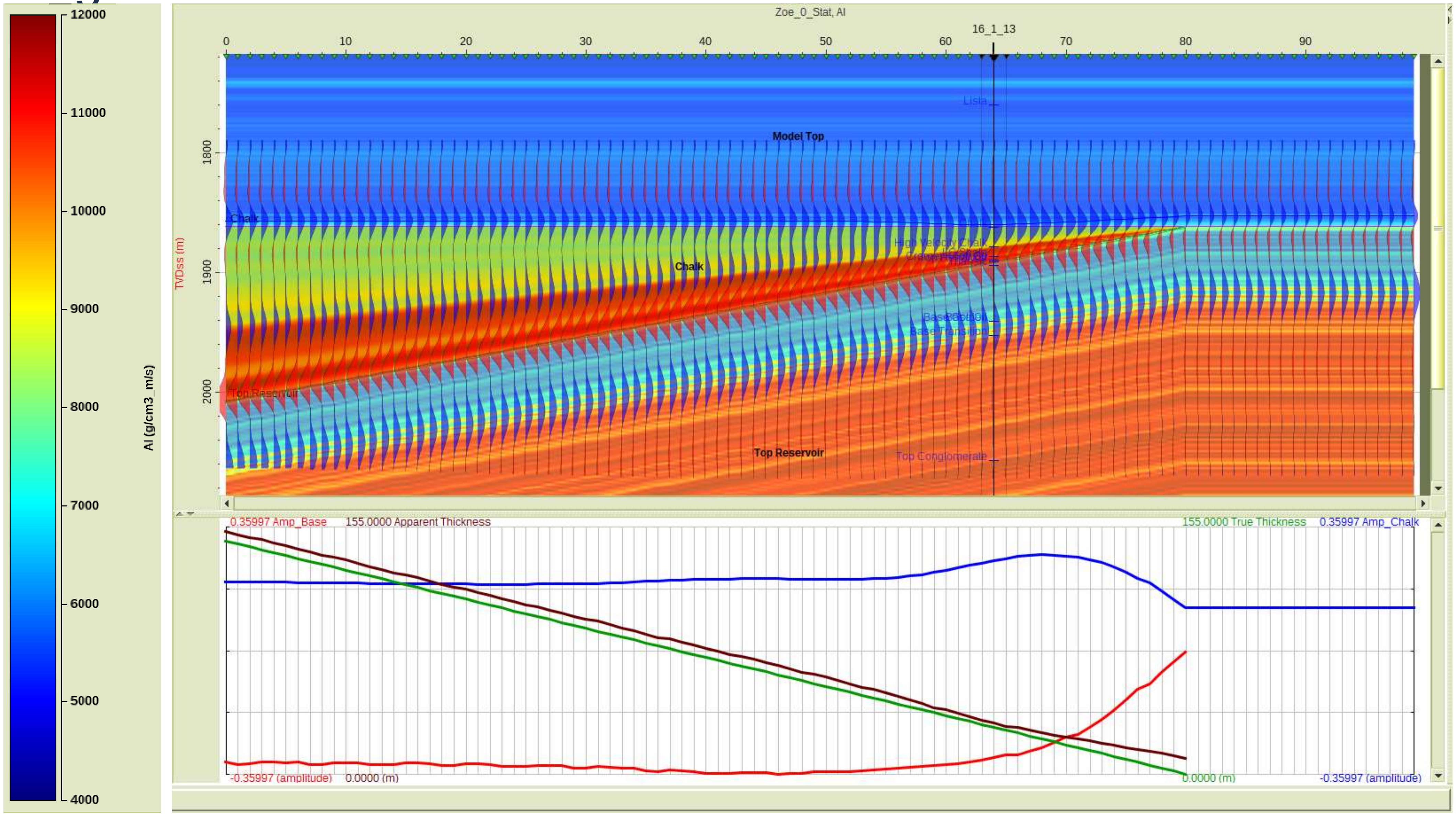
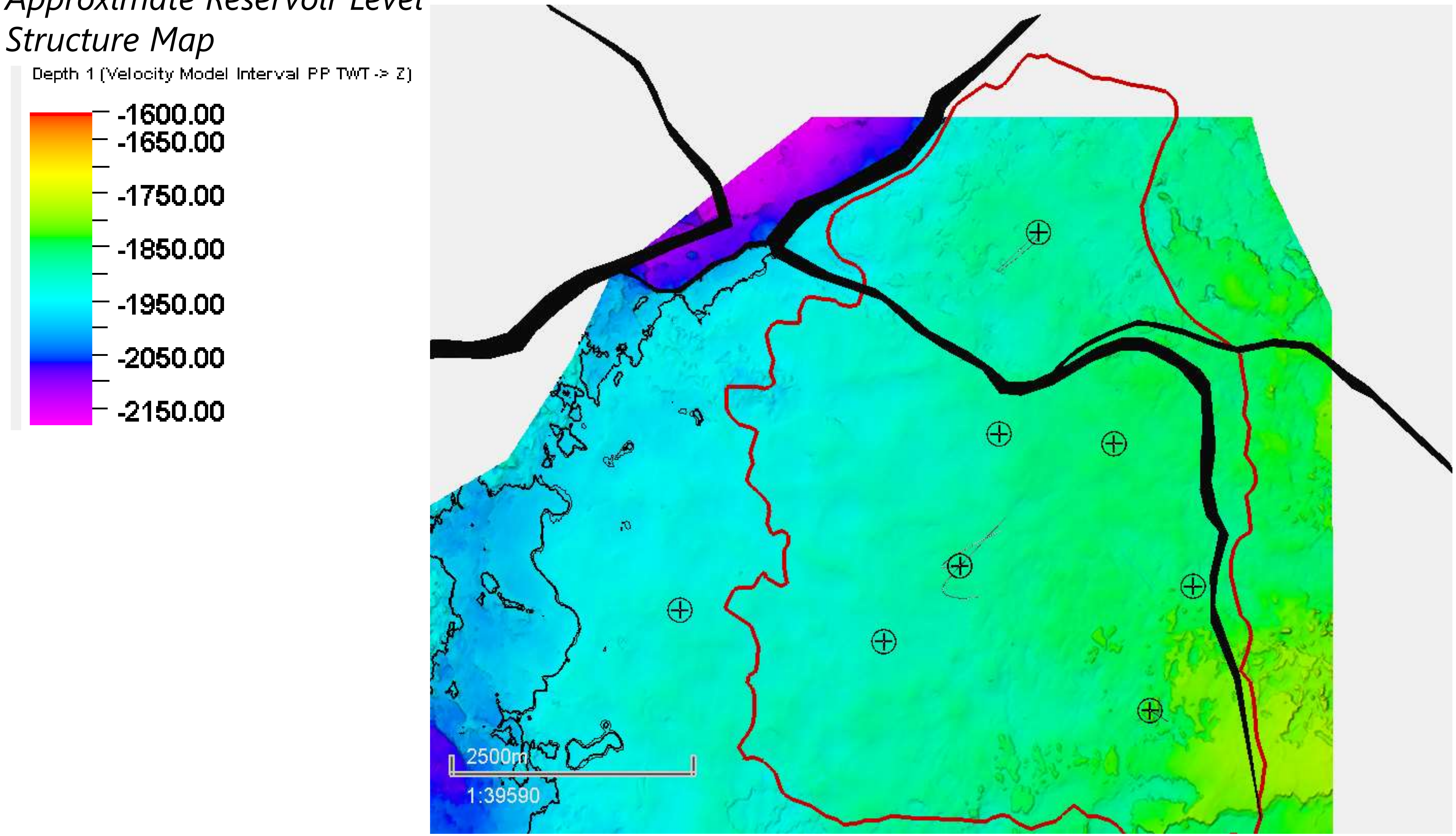


“Common” OWC: 1939mTVDSS

Approximate Reservoir Level Structure Map



Lateral Variability in Wavelet 500ms window around reservoir

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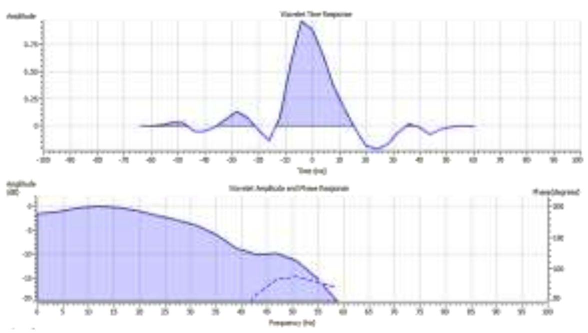
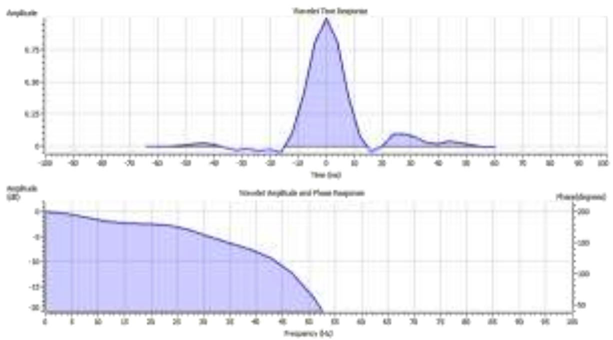
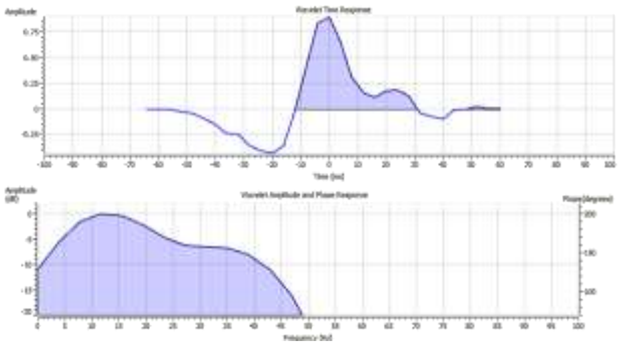
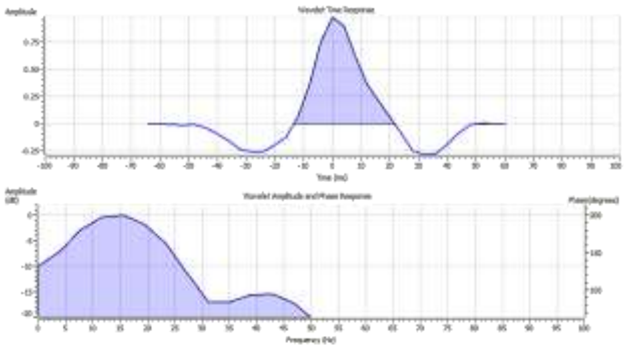
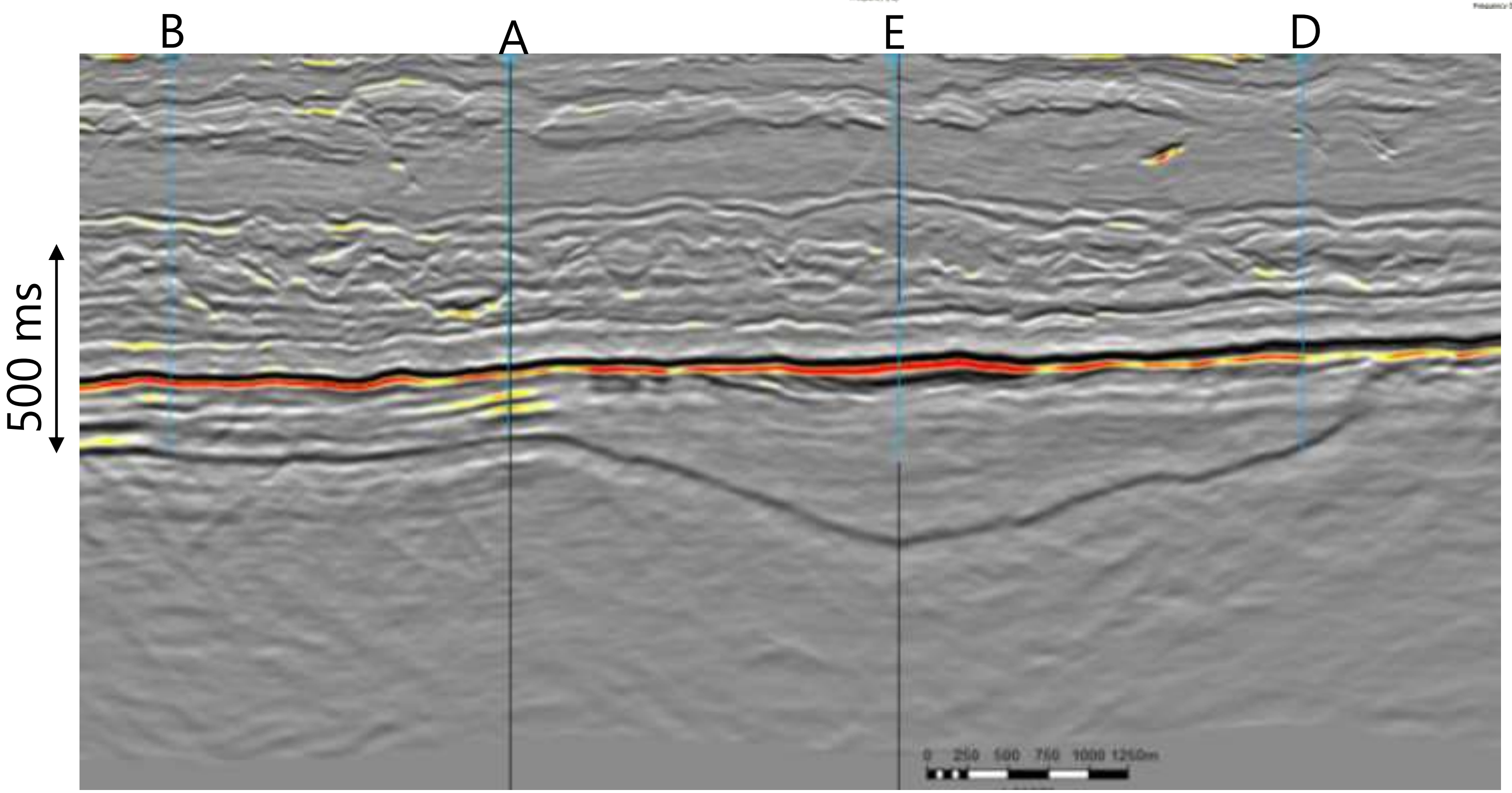
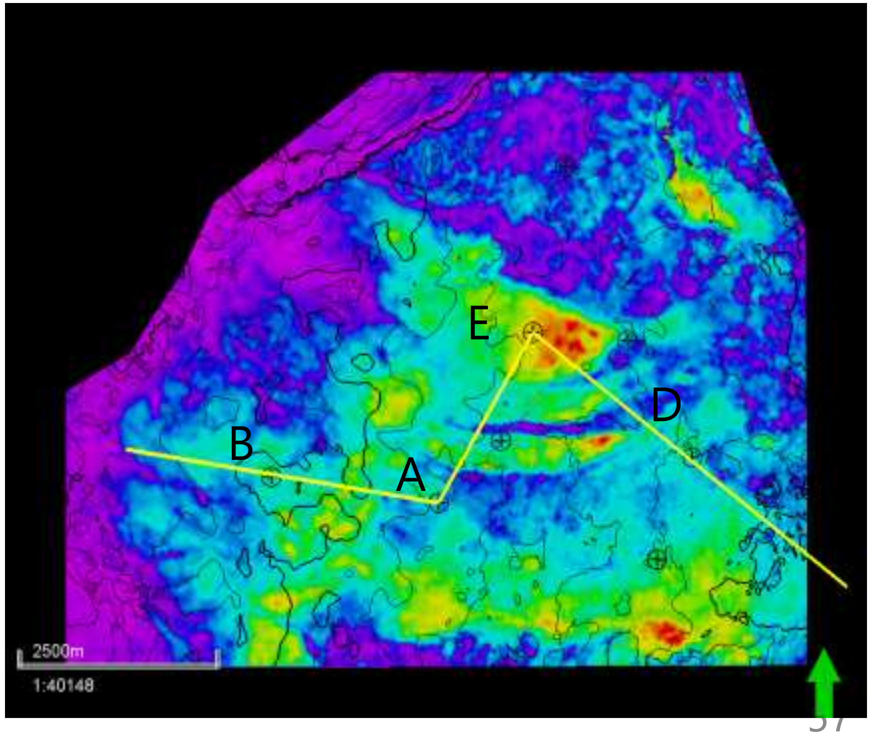










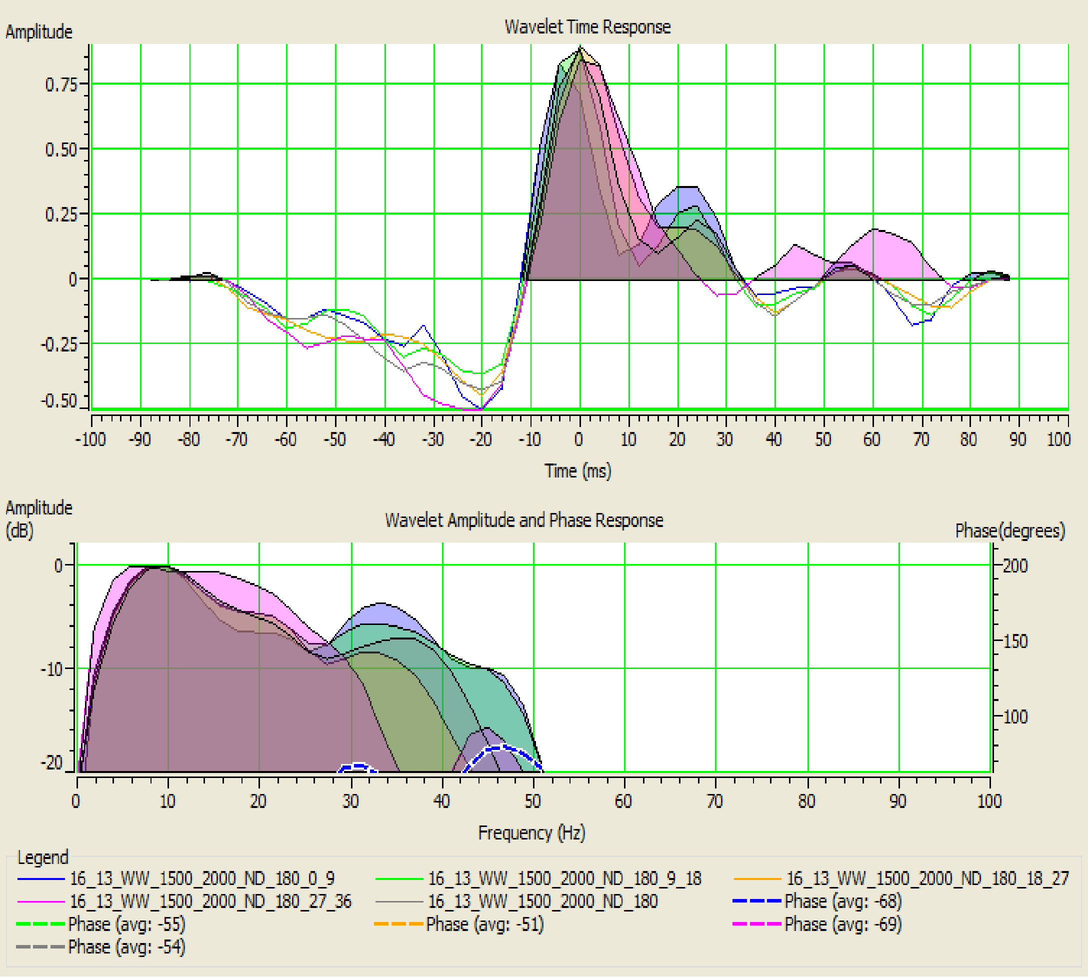


Wavelet Variability: Deterministic 16/1-13

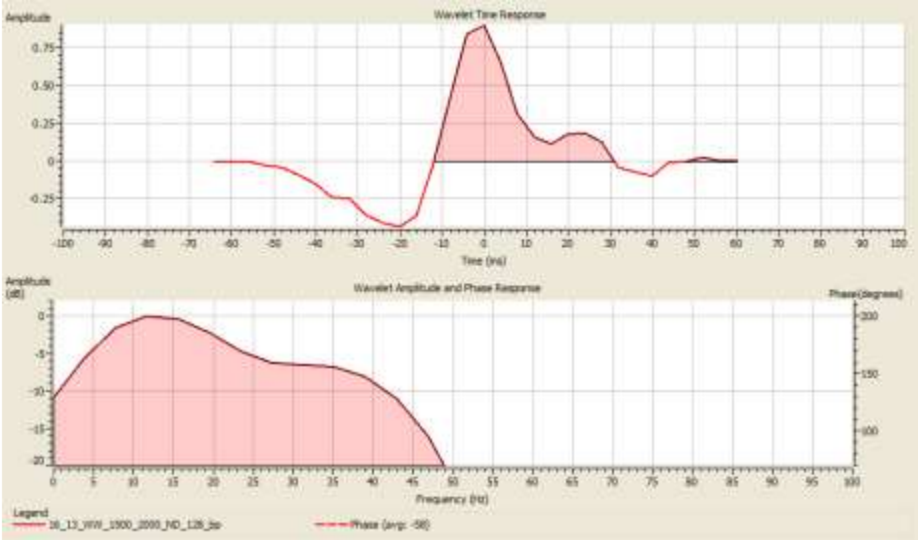
- Tests
  1. Potential Issues with Stack
  2. Transmission Issues
  3. Time-Depth Relationship

Angle Stack Check

With Varying Angle Range



Full Stack



Transmission Issue Check

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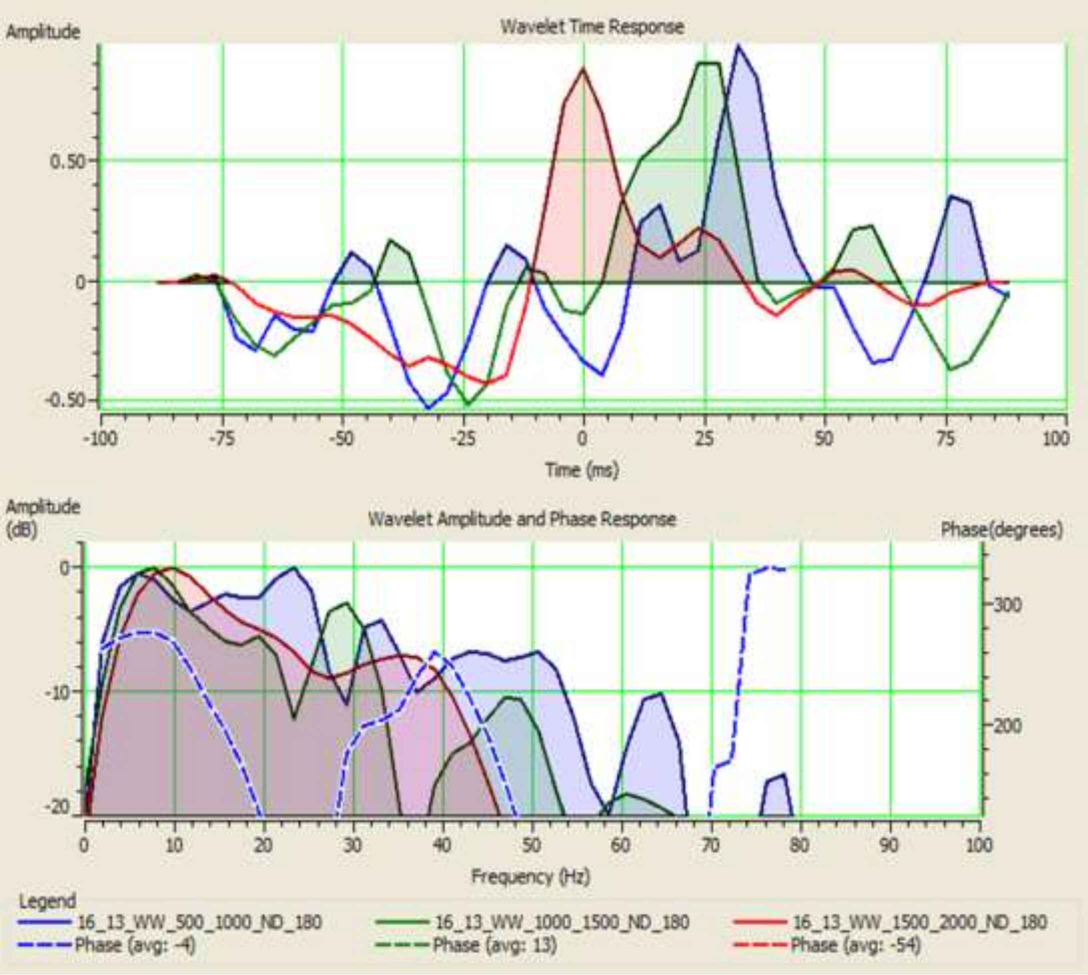
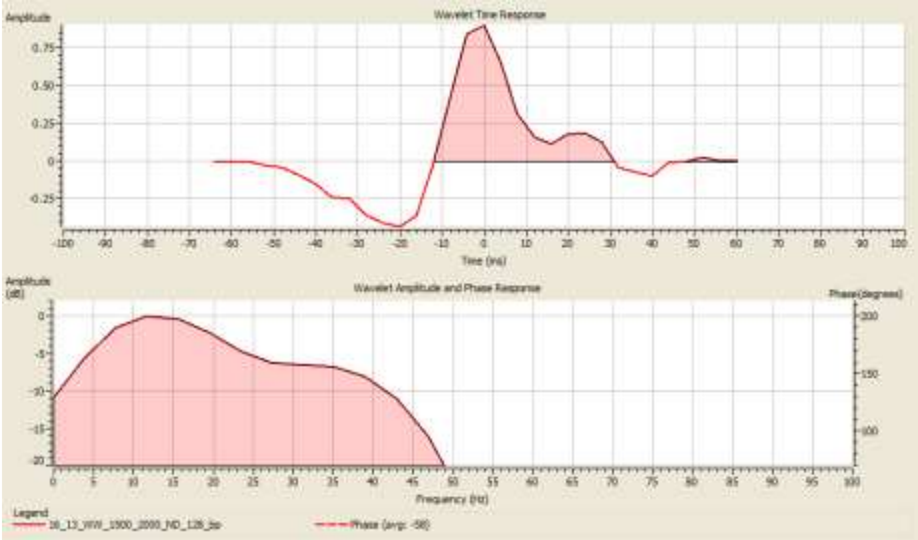
With Varying Depth

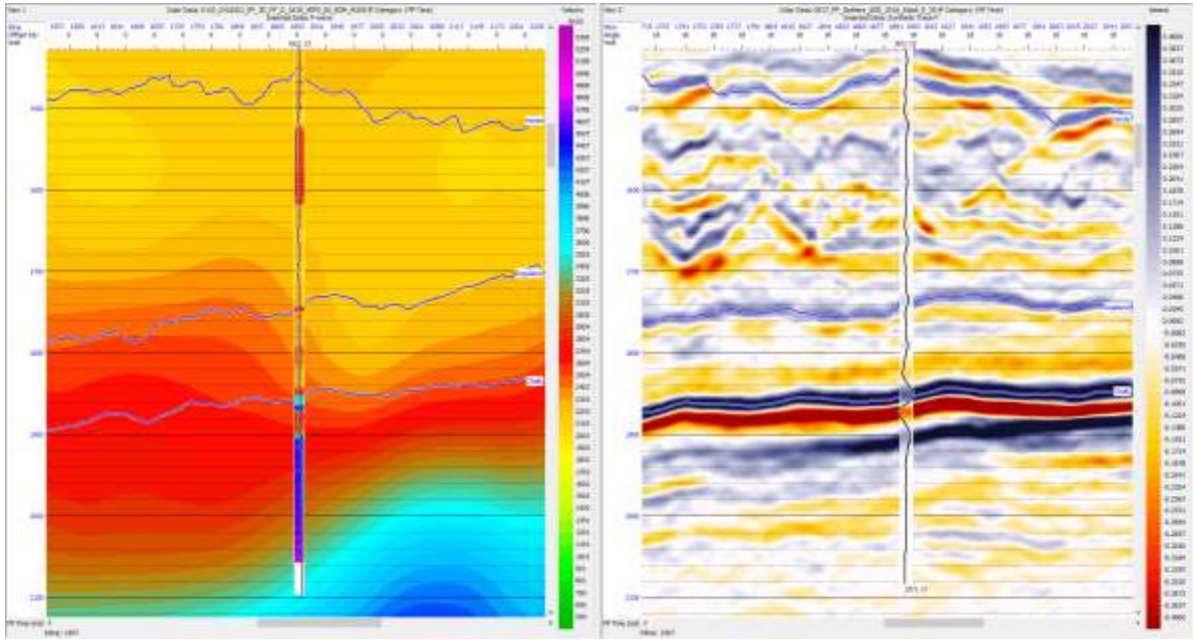


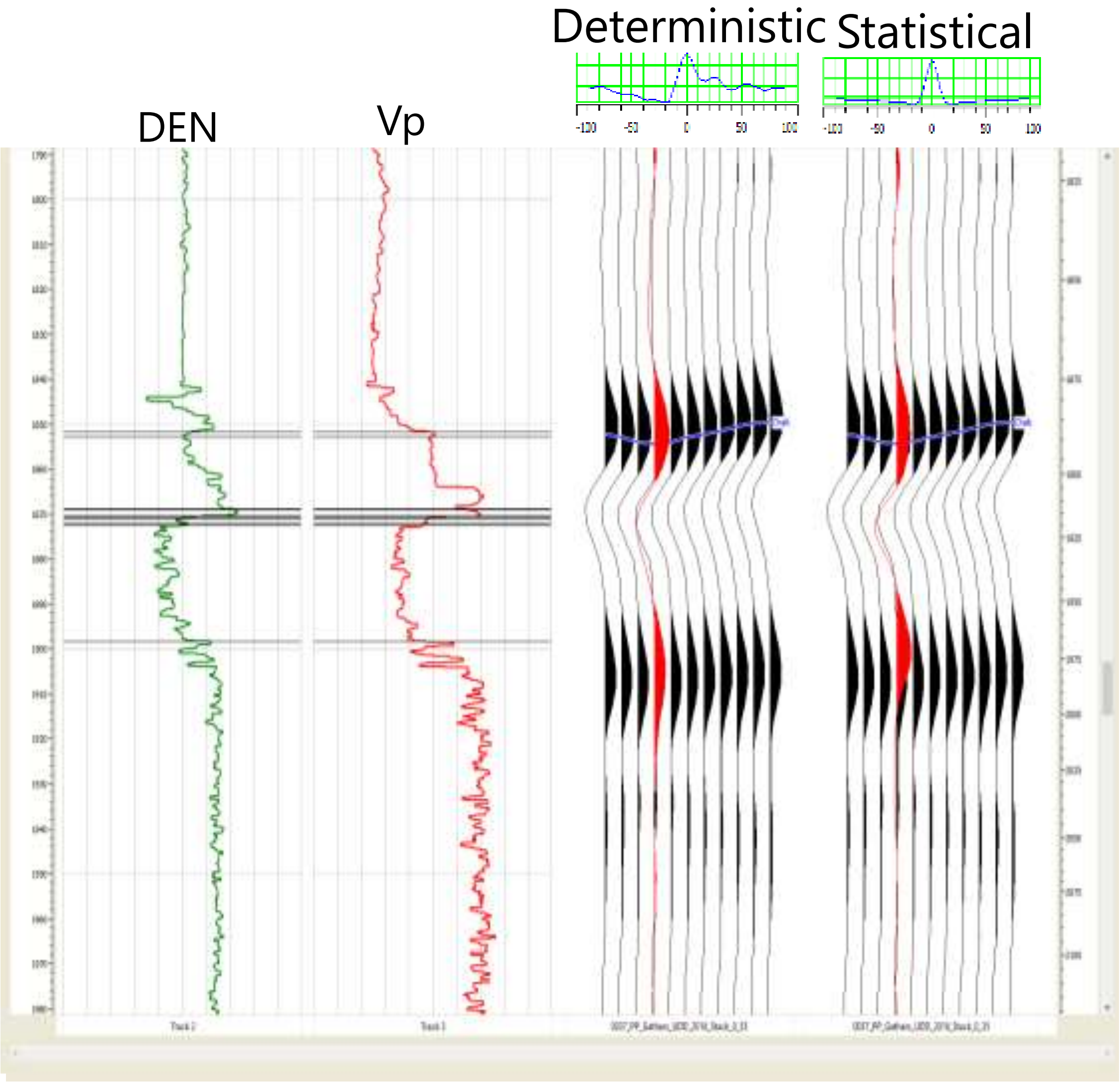
Full Stack



Time-Depth

- Time shifts in base reservoir from deviations in velocity model may translate into phase shift in extracted wavelet

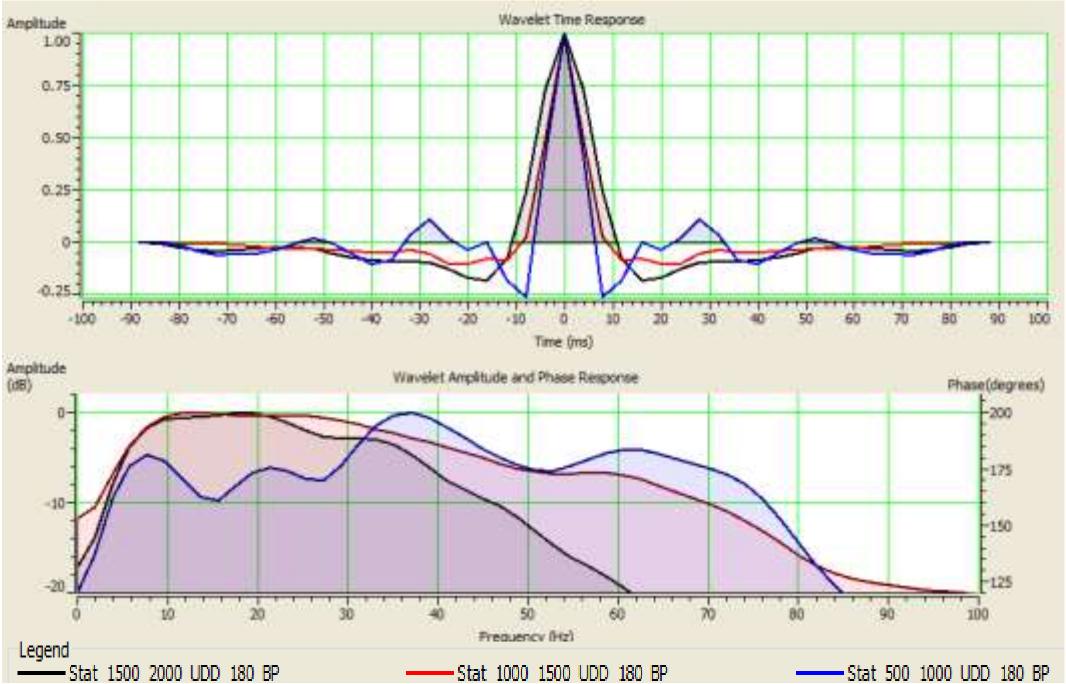




Wavelet Variability: Statistical

- Wavelet sidelobes become unusual with depth- transmission issues
- However statistical wavelet can still capture reservoir zone in well reasonably well given phase
  - Trouble in base reservoir

With Depth Range



Time-Depth Relationship Check: Well E

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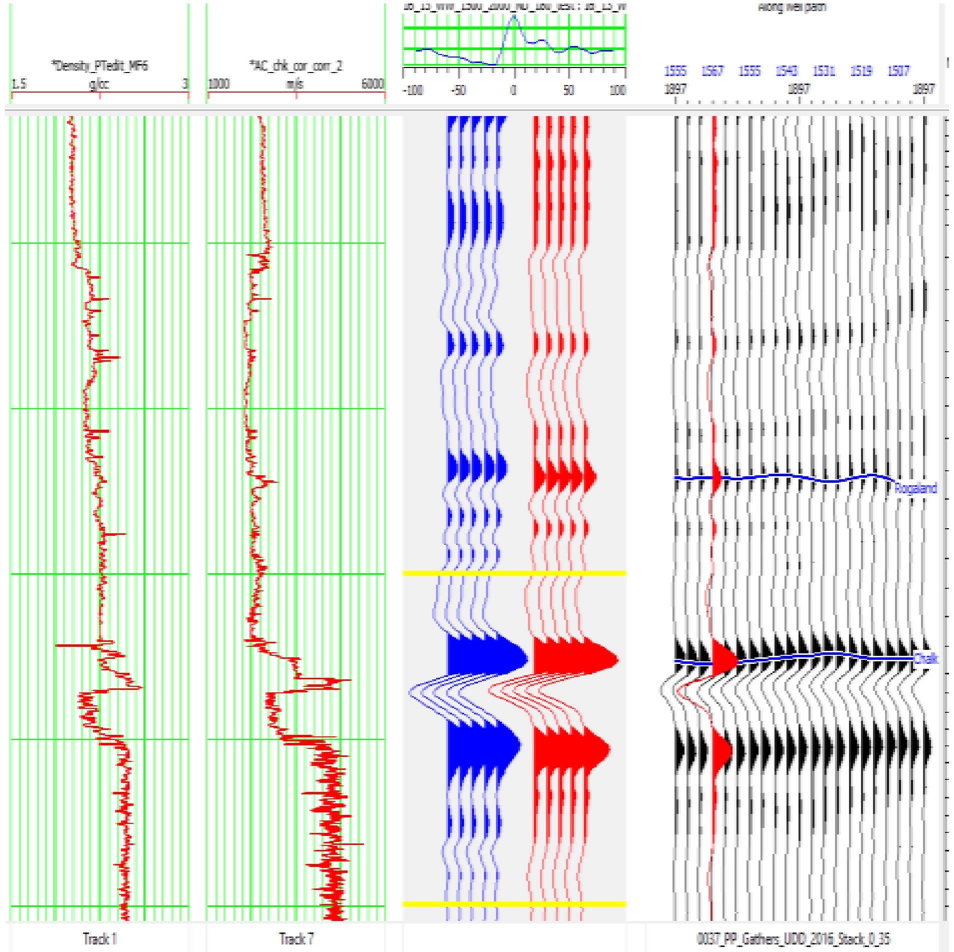
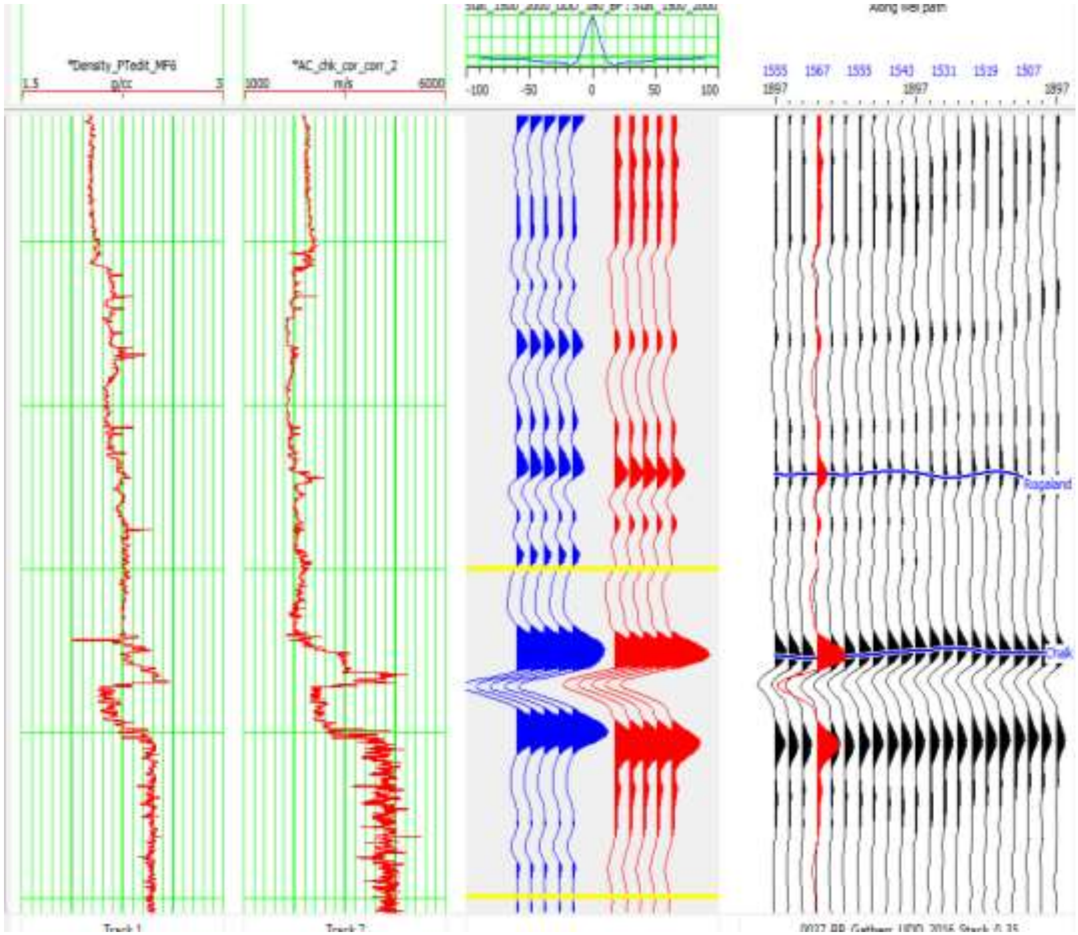
.953 CC Wavelet: Deterministic 180ms BP

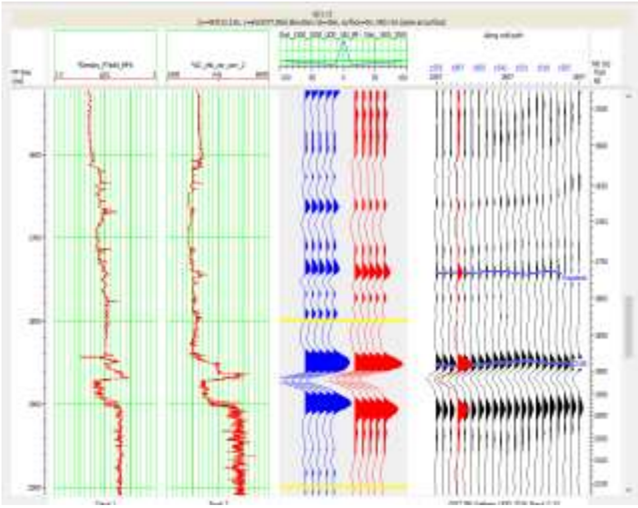


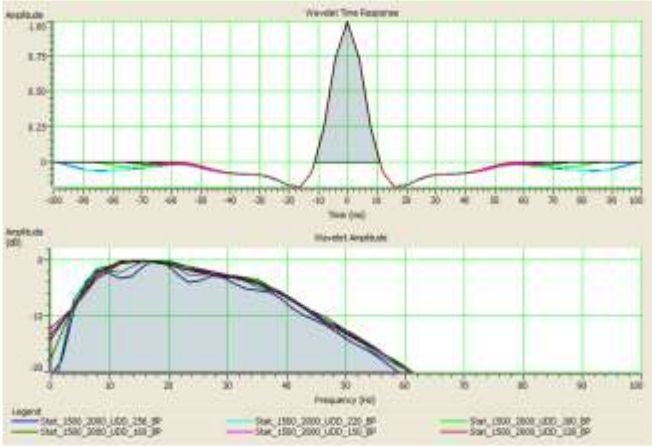
.871CC Wavelet: Statistical 180ms BP

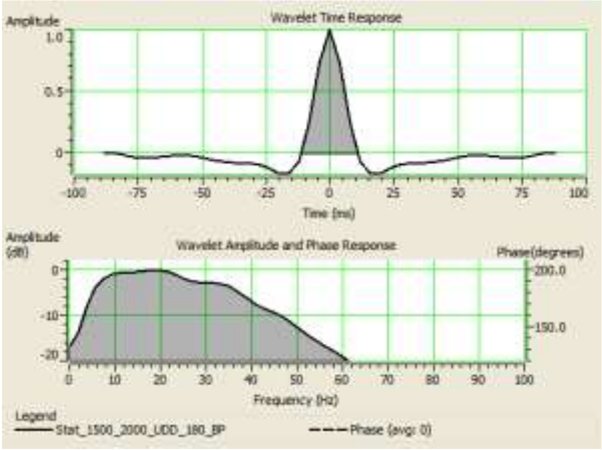


Wavelet Variability: Deterministic 16/1-13

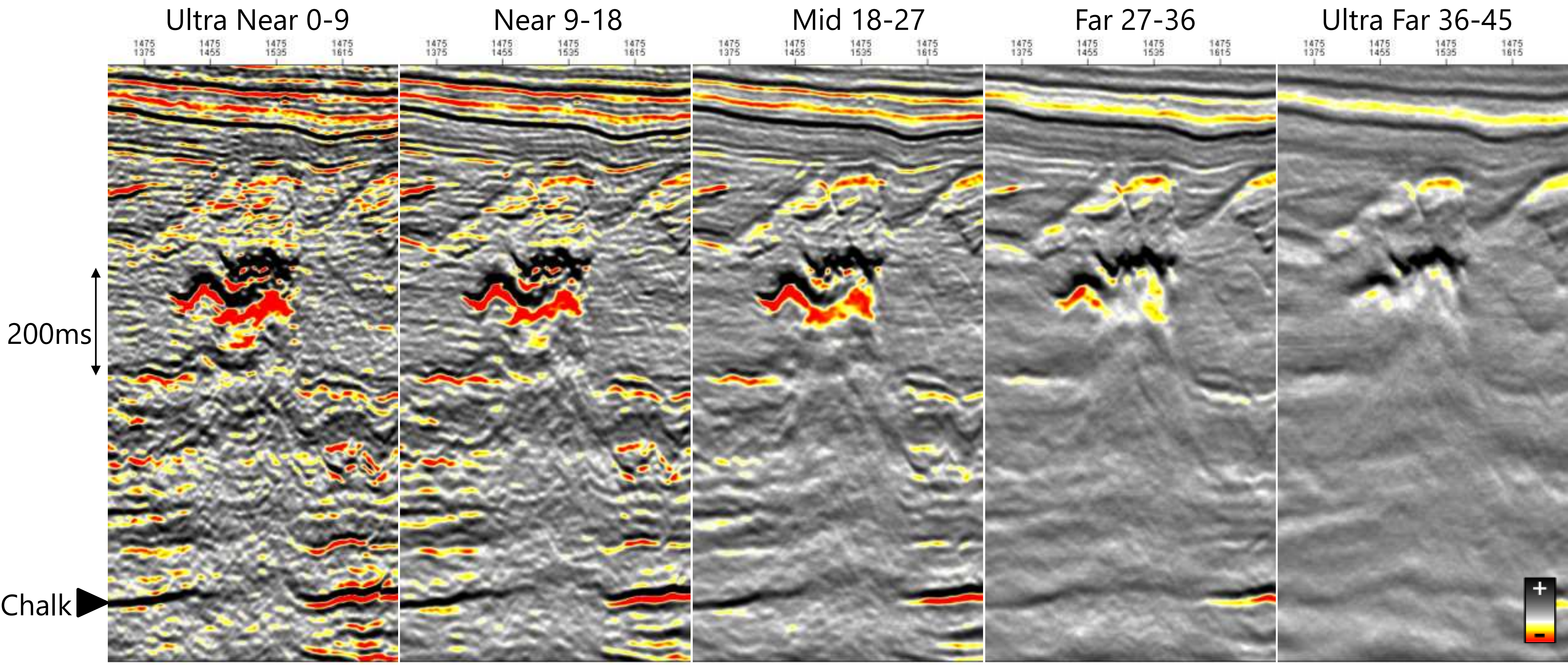
- Tests
  1. Time-Depth Relationship
  2. Potential Issues with Stack
  3. Transmission Issues
- Conclusion: Utilize a Statistical Wavelet
  - Statistical still correlates with log
  - All other wells are close to zero phase
  - Velocity Model variation in non-zero phase well



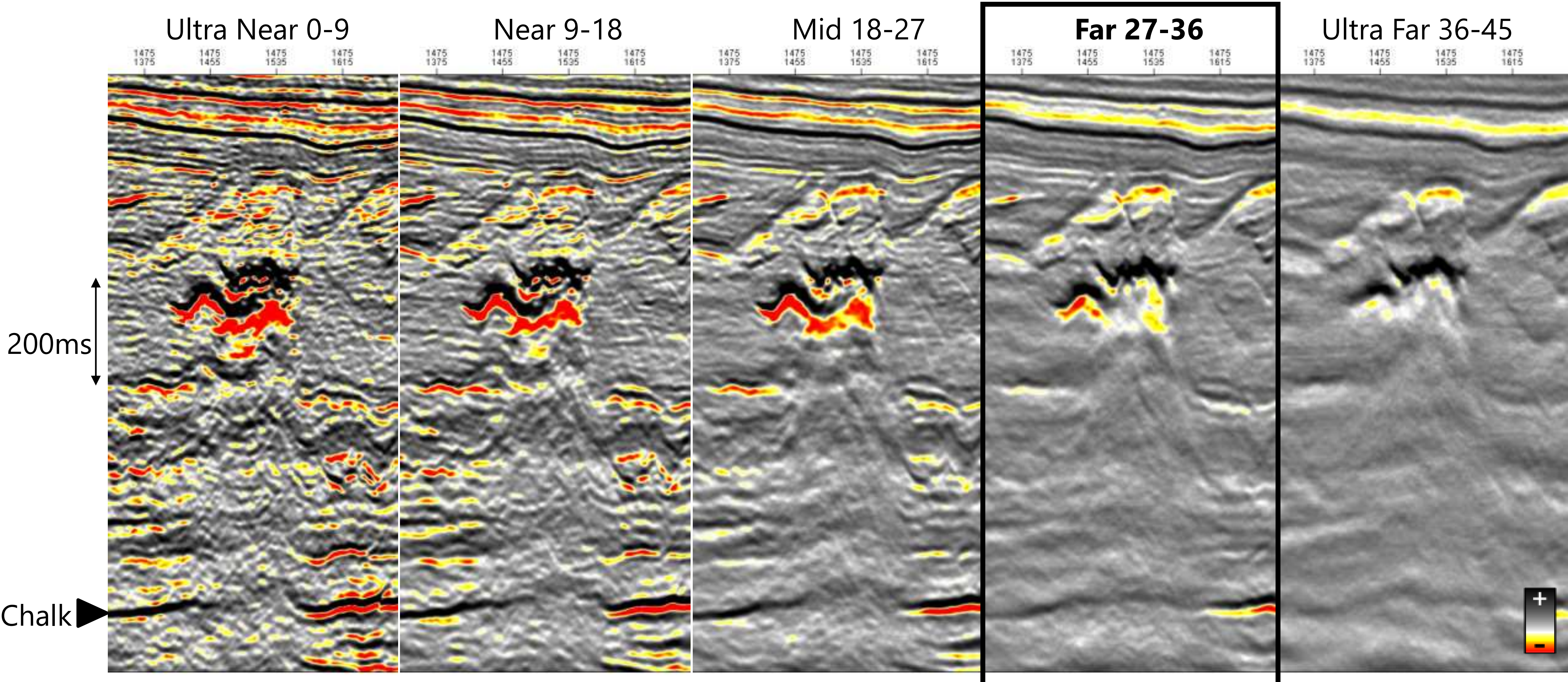




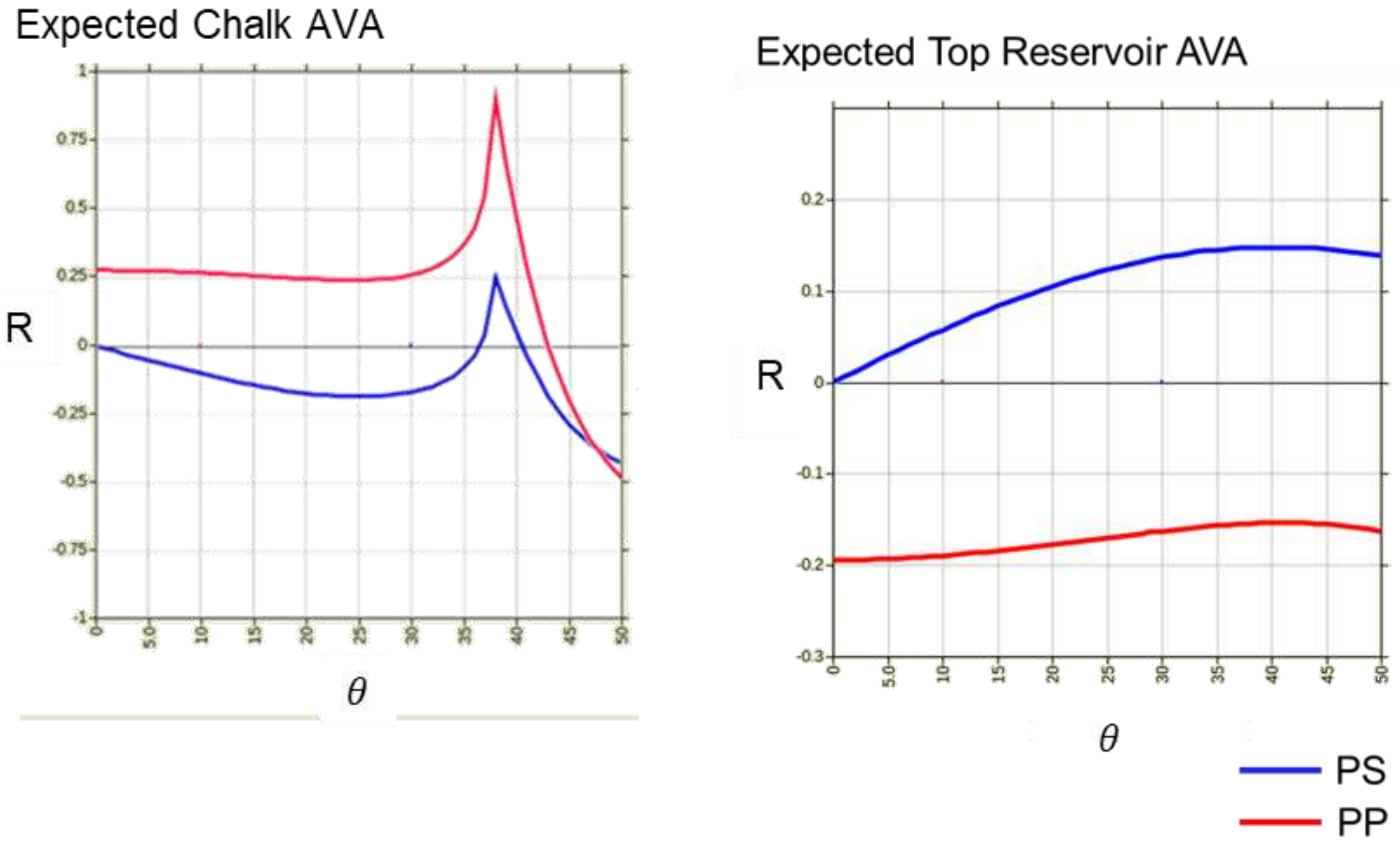
Transmission Path Obstacles: Cemented Sands

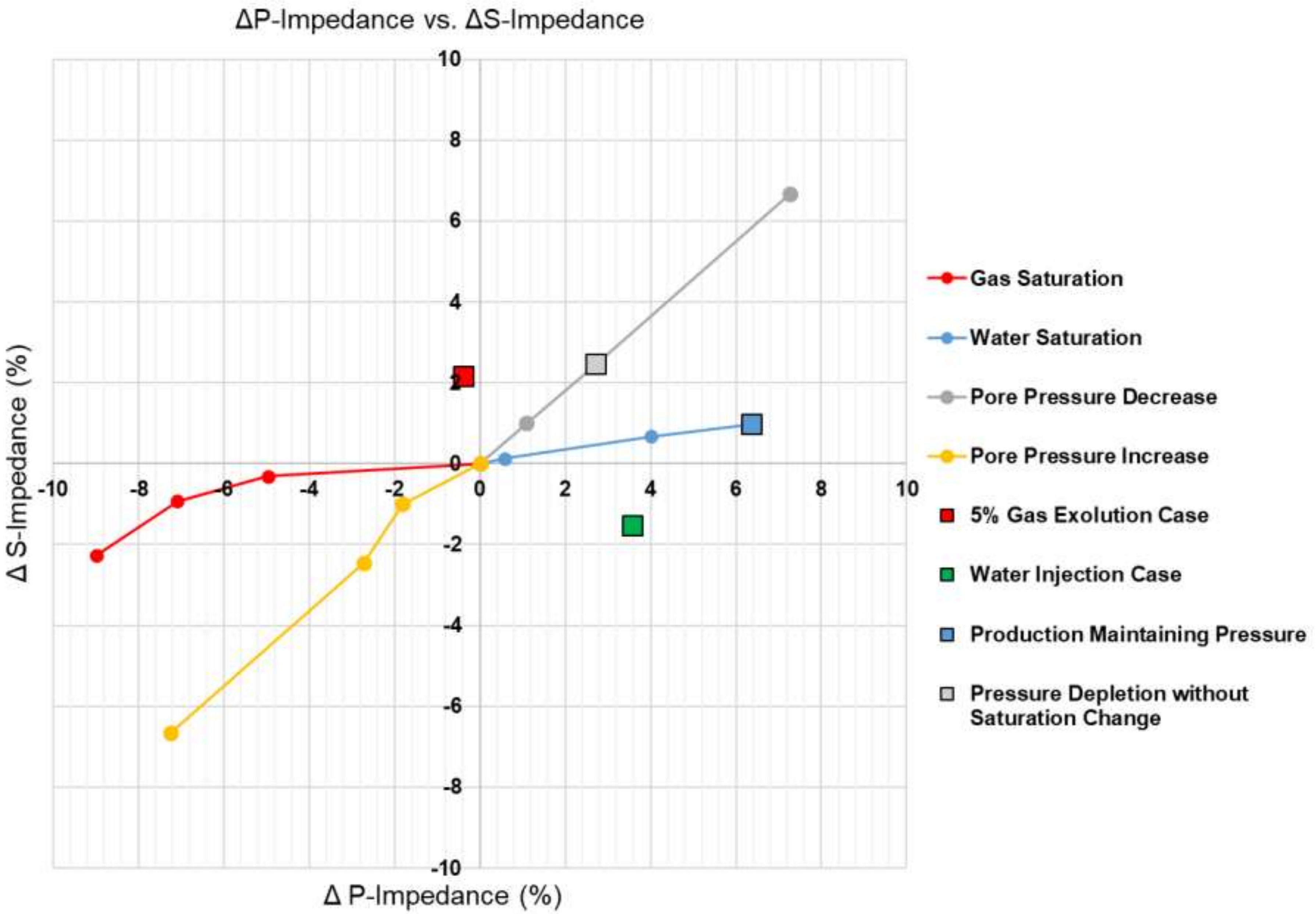


Transmission Path Obstacles: Cemented Sands



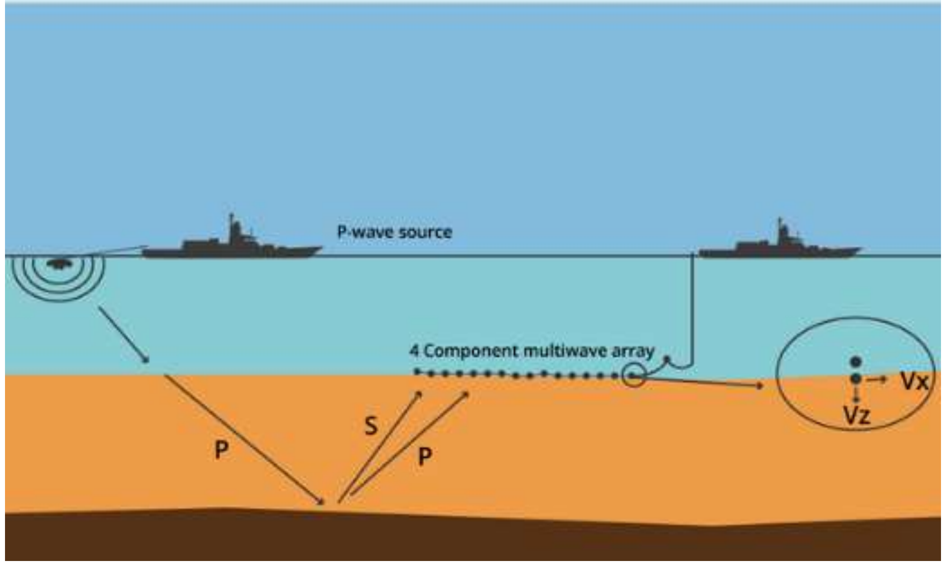
Simple Block Model

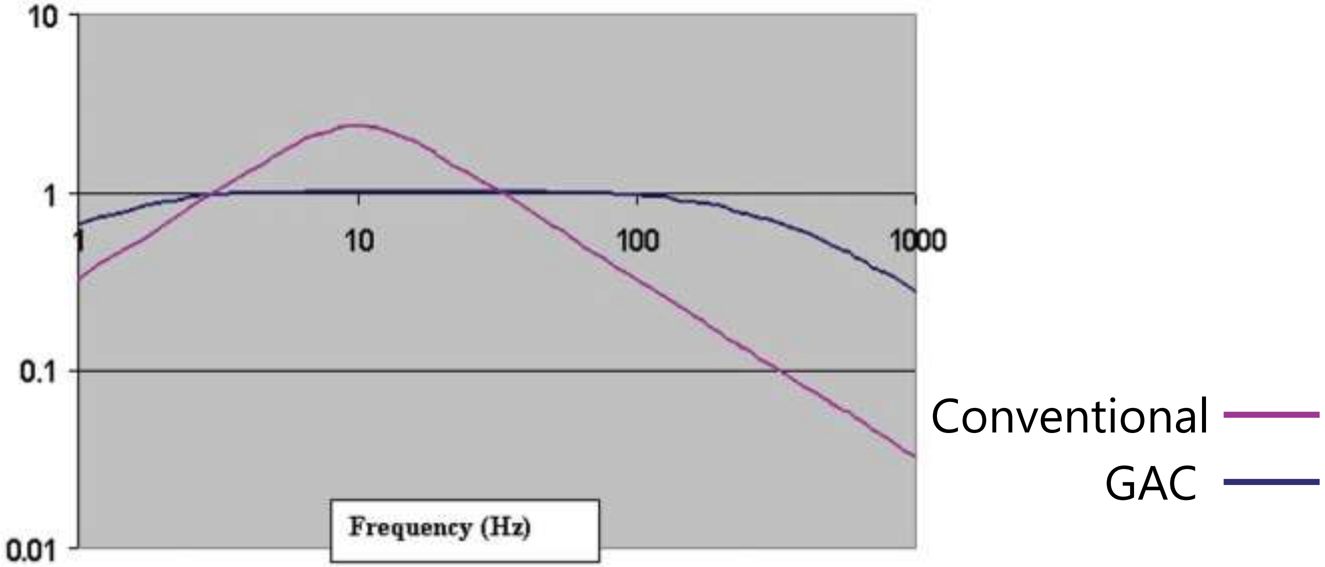



ΔP-Impedance vs. ΔS-Impedance
Δ S-Impedance (%)
Δ P-Impedance (%)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-10
-8
-6
-4
-2
0
2
4
6
8
10
Gas Saturation
Water Saturation
Pore Pressure Decrease
Pore Pressure Increase
5% Gas Exolution Case
Water Injection Case
Production Maintaining Pressure
Pressure Depletion without Saturation Change

Q-Seabed Cables, WesternGeco

- Source boat + Receiver towing boat
- Reciever tows a max of 4 cables
- Conventional geophones in previous OBC systems are replaced by geophone accelerometers(GAC) that have an improved frequency response for low and high frequency end of the spectrum





Moldoveanu, 2006

Using the Velocity Model for LFBM