RESERVOIR CHARACTERIZATION PROJECT

Raudhatain Field Project, North Kuwait

Nadima Dwihusna and Liwei Cheng

November 14th, 2019

COLORADOSCHOOLOFMINES

RESERVOIR CHARACTERIZATION PROJECT

Rock Physics Analysis and Post Stack Inversion in Raudhatain Field, North Kuwait

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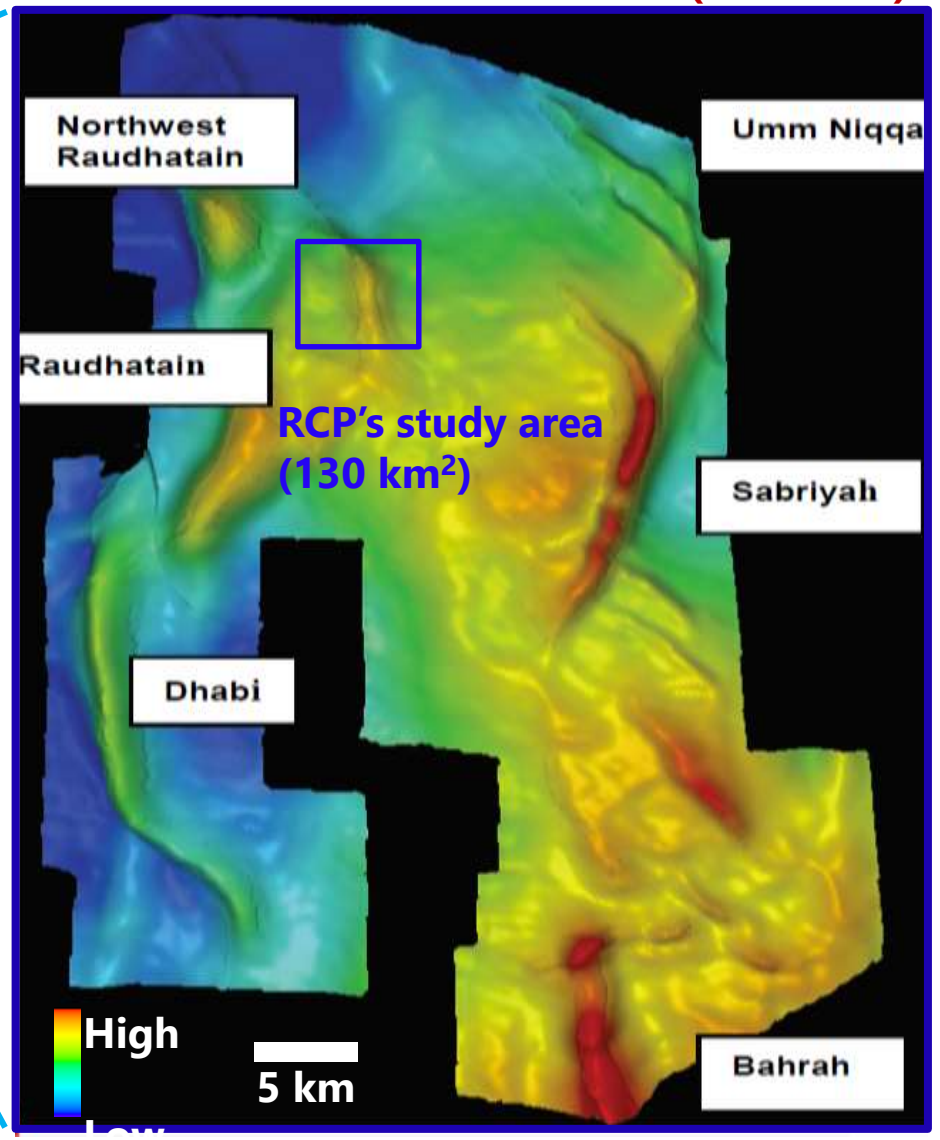
Outline

- Introduction of Raudhatain field
- Overburden velocity and ray tracing model
- Rock physics analysis
- Post stack seismic inversion

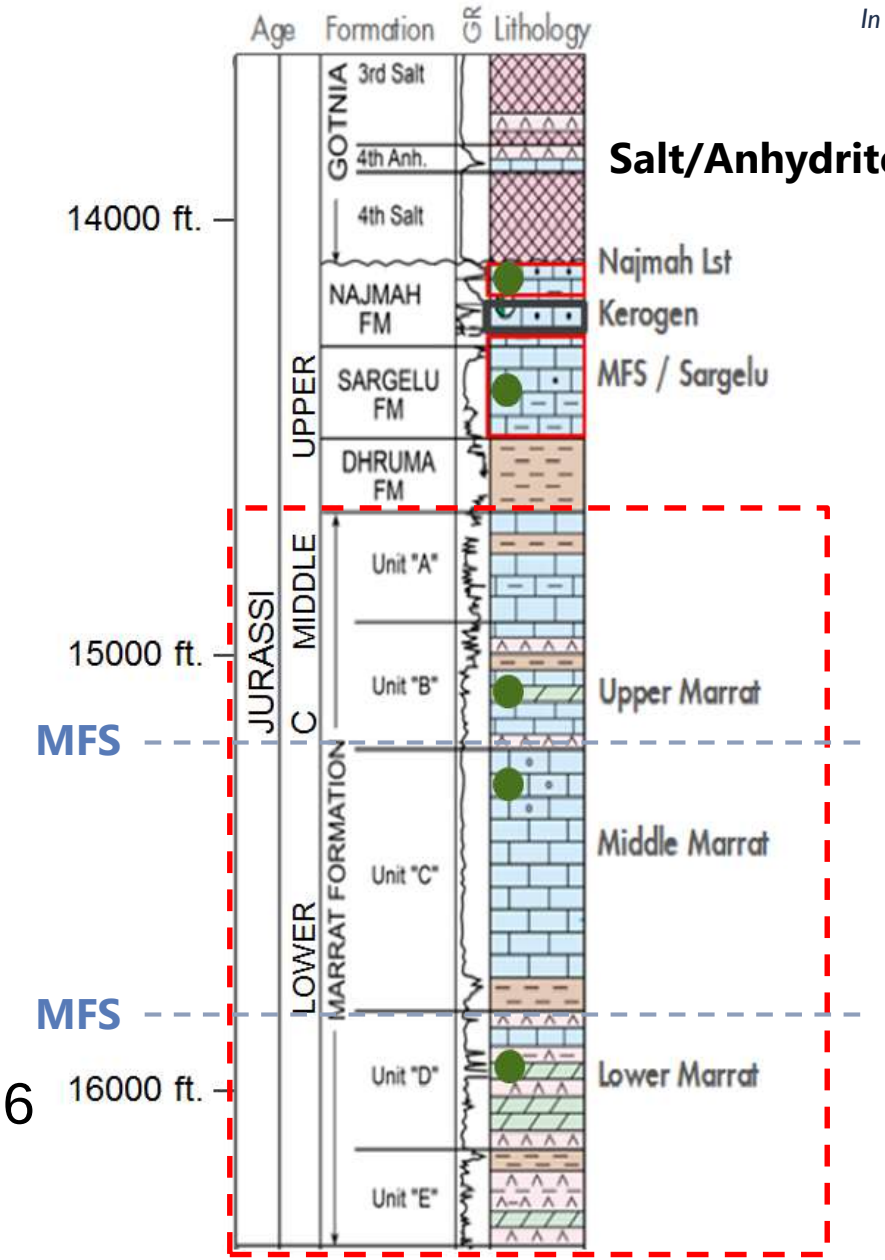
Raudhatain Field



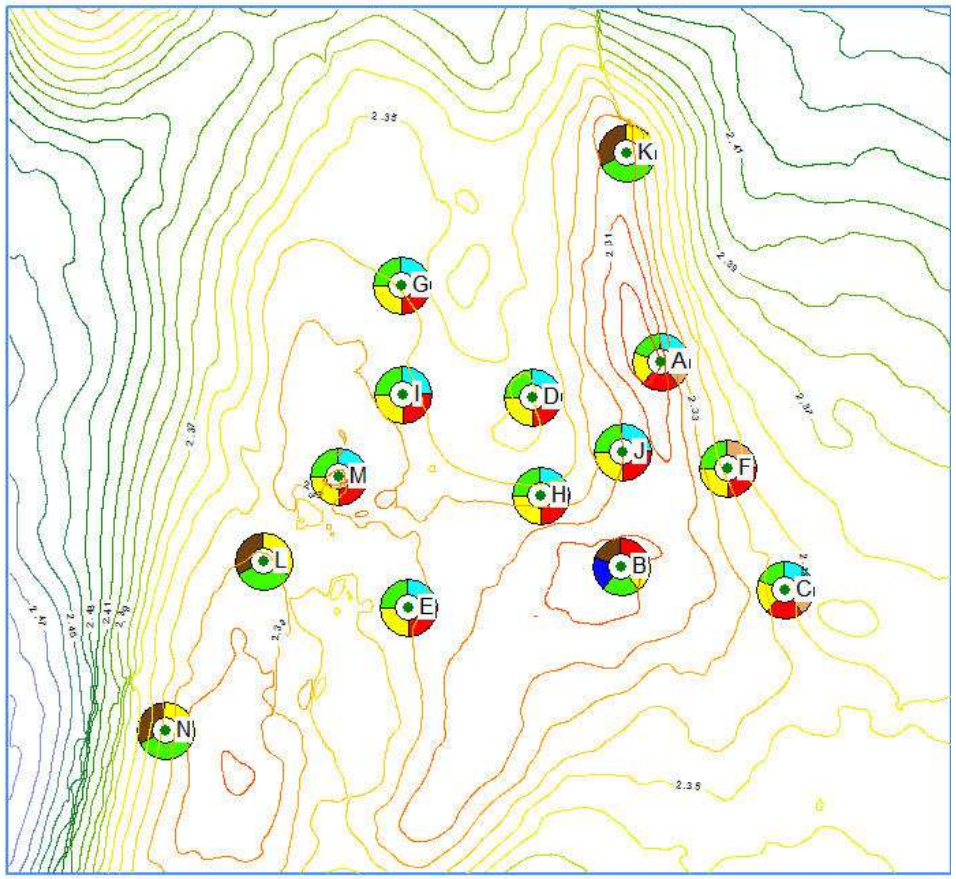
(Top of Najmah time structure map, modified from Al-Eidan, 2010)

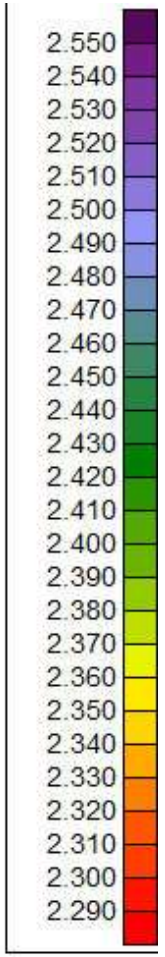
Marrat Formation

- Deposited on carbonate-evaporite platform during Early Jurassic age
- Total thickness is up to 2,000 ft
- Middle Marrat (MMR) is the most prolific unit and consists of a sequence of limestones, frequently with anhydrite, dolomite and rare shale
- Total porosity is up to 20%
- Production from 2,500 to 5,000 bopd and from 6 to 20 MMscfd per well



Data



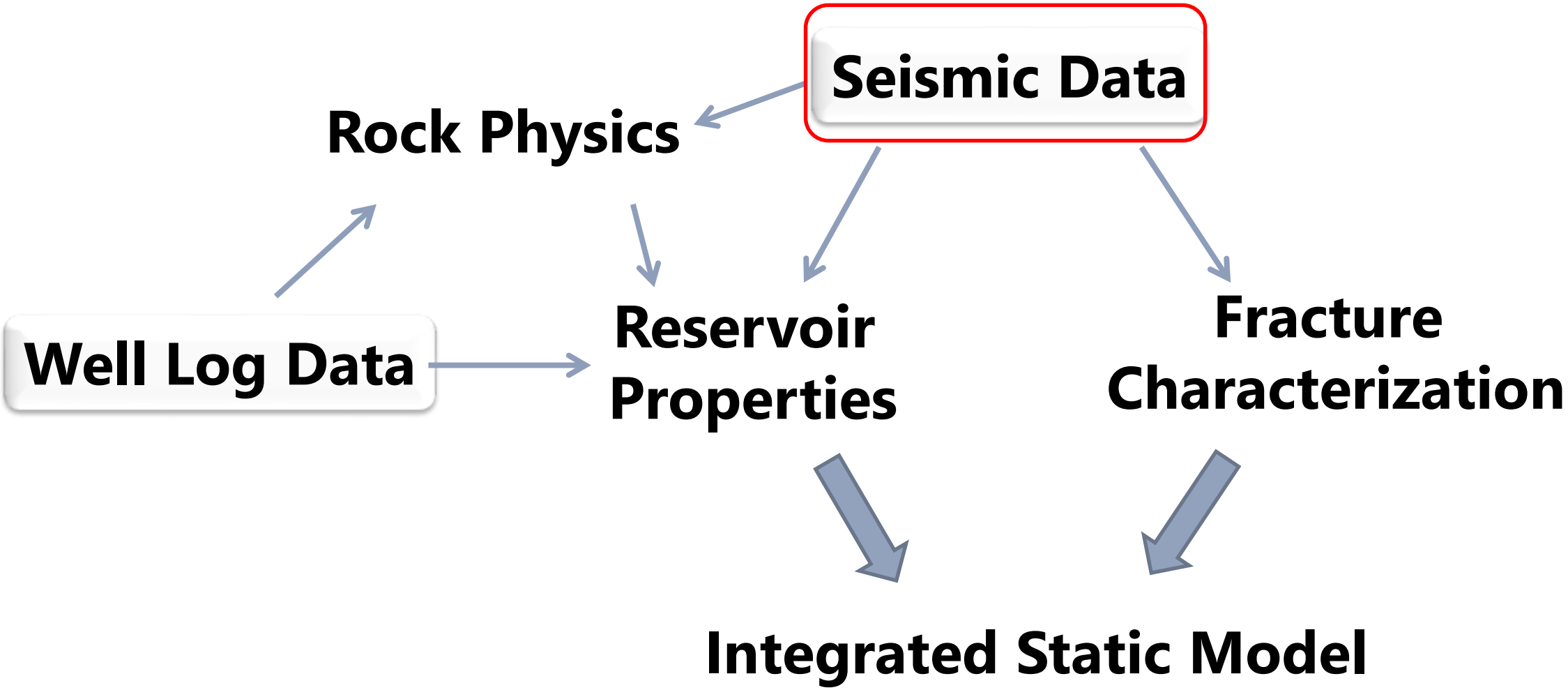


Najmah kerogen
Time structure (s)

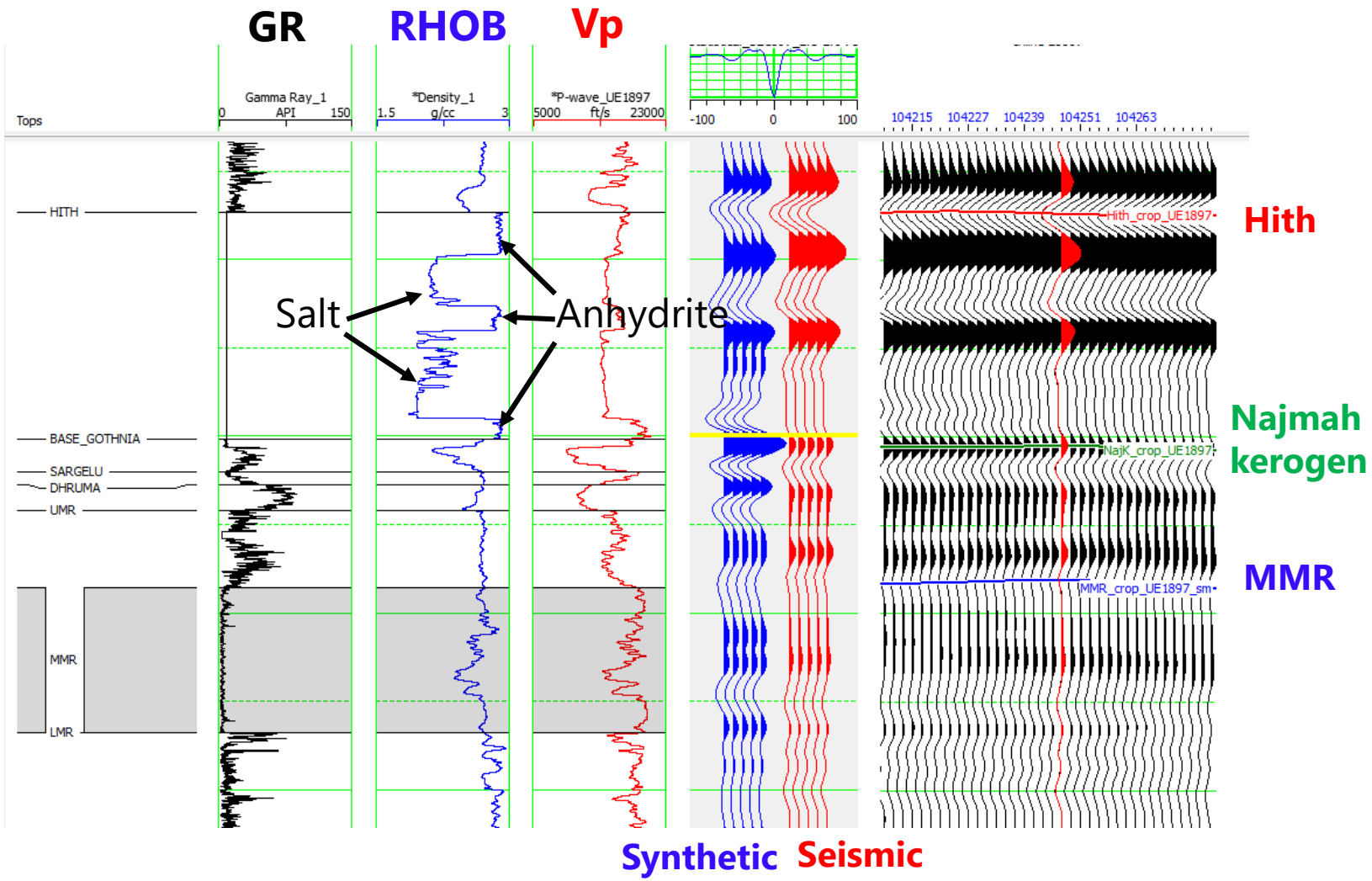
ZVSP IS PRESENT
3DVSP IS PRESENT
DTCO IS PRESENT
RHOB IS PRESENT
GR IS PRESENT
NPHI IS PRESENT
AT90 IS PRESENT

1.5 km

Reservoir Characterization

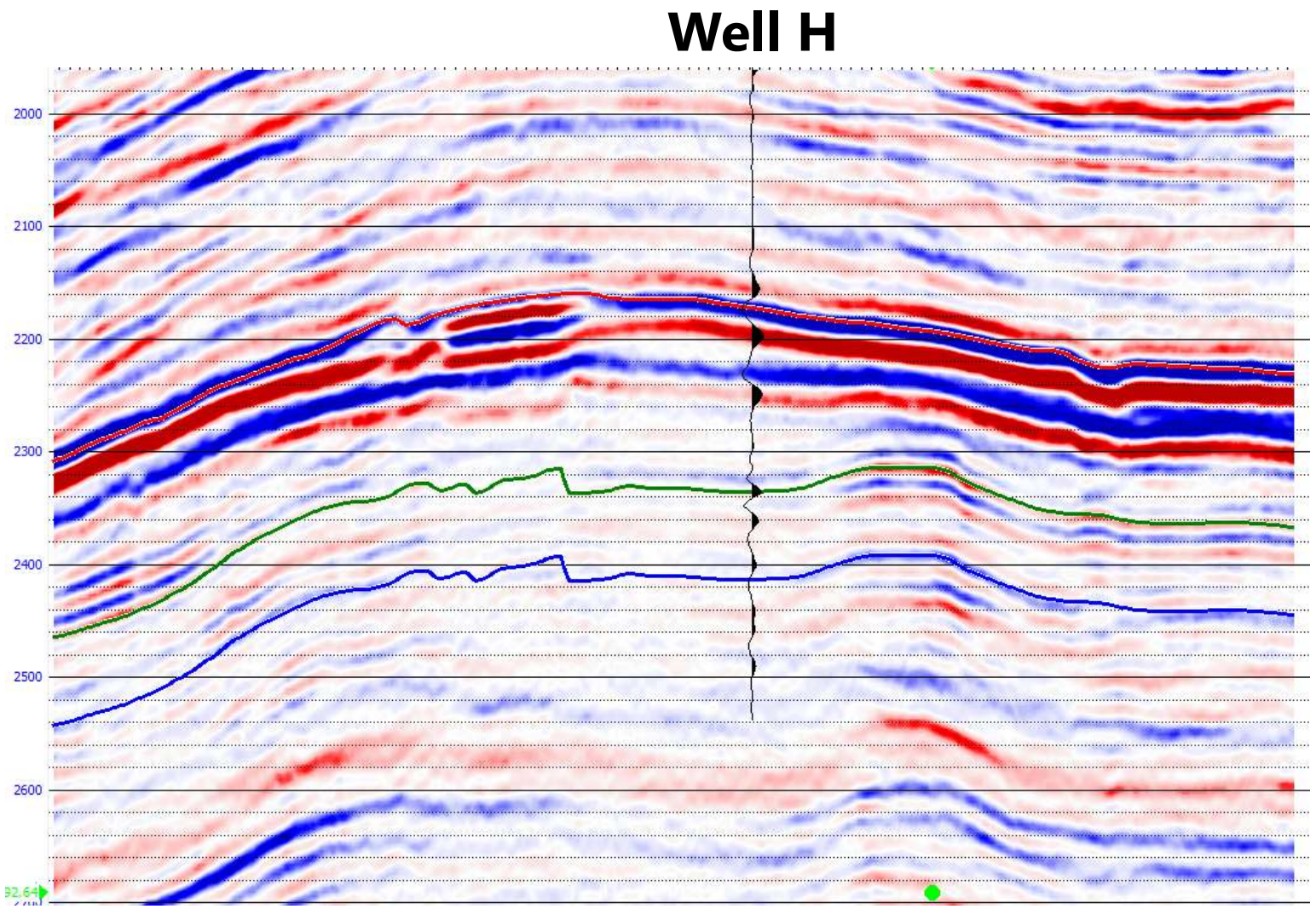


Seismic-well Tie at Well B



Correlation coefficient (from Najmah Kerogen to TD) = 0.686

Amplitude Issue Under Salt/Anhydrite



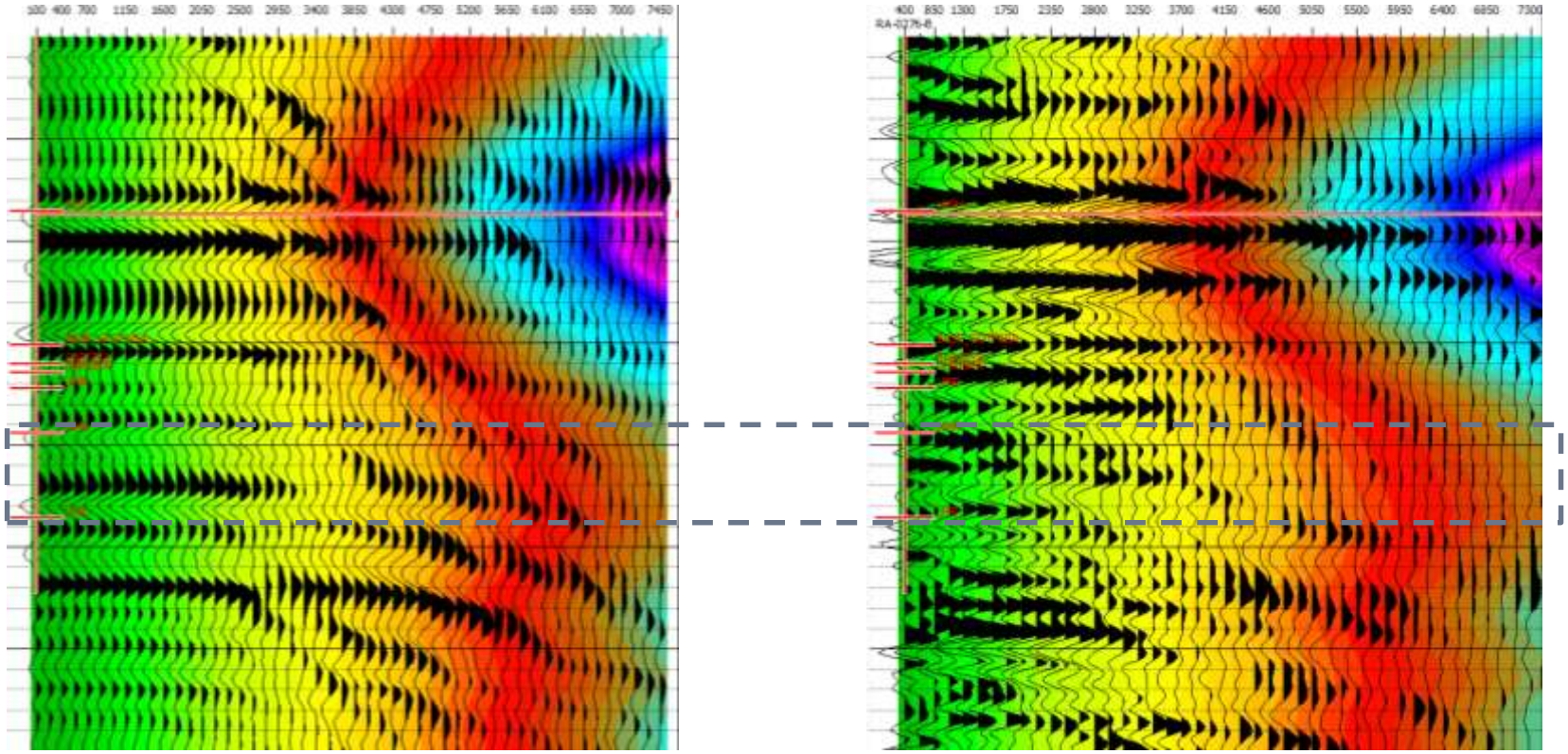
Elastic Reflectivity Model and Field Data

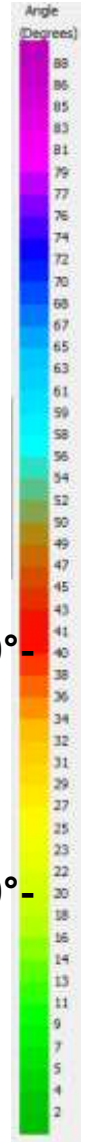
Primaries + multiples + converted waves

Surface seismic data

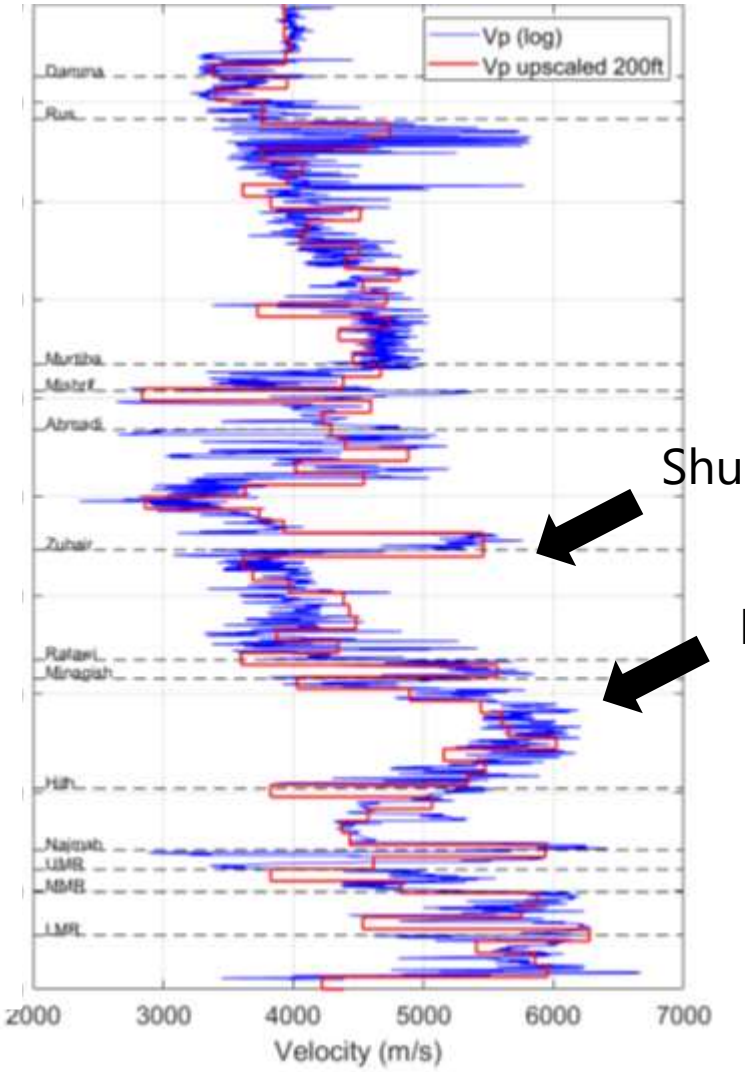
Hith

MMR





High Velocity Overburden Layer



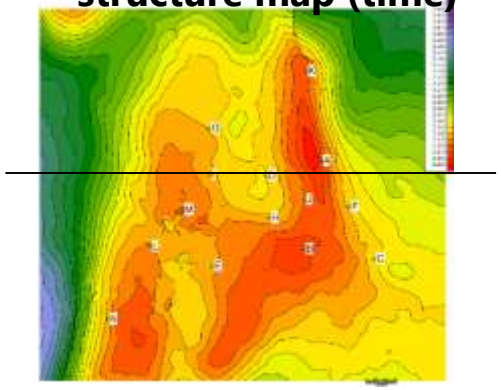
Shu'aiba carbonate

Minagish carbonate

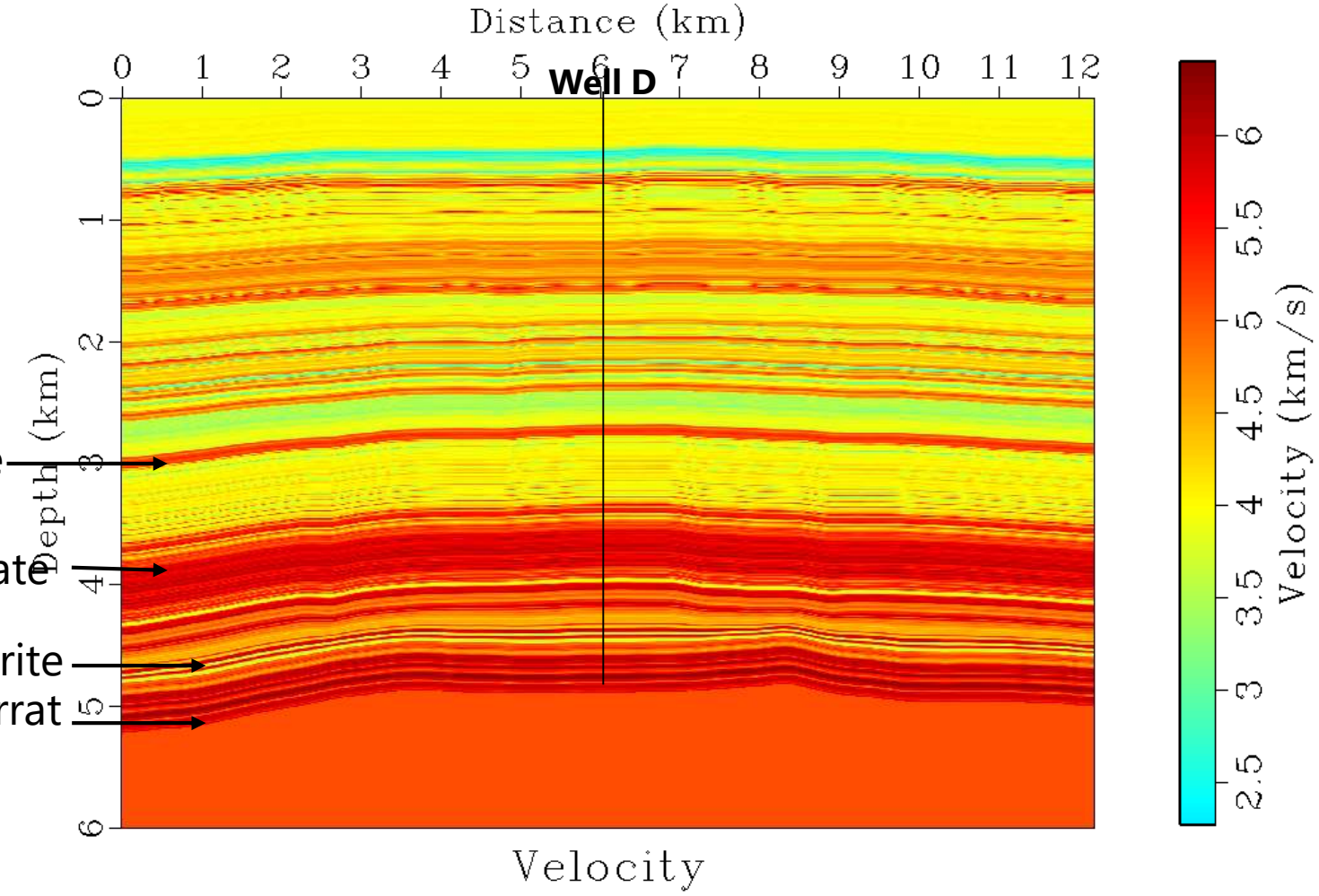
MMR

2D Velocity Model

Najmah Kerogen structure map (time)

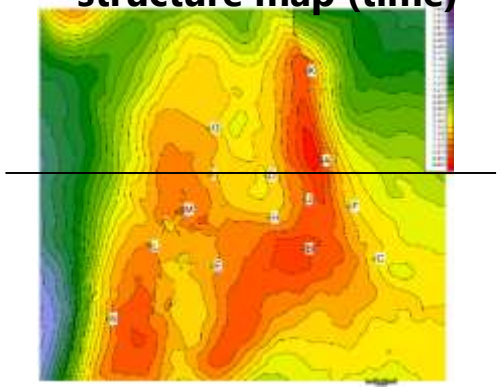


Velocity sample interval: 20 m



2D Velocity Ray Tracing Model

Najmah Kerogen structure map (time)



5 by 5 smoothing applied

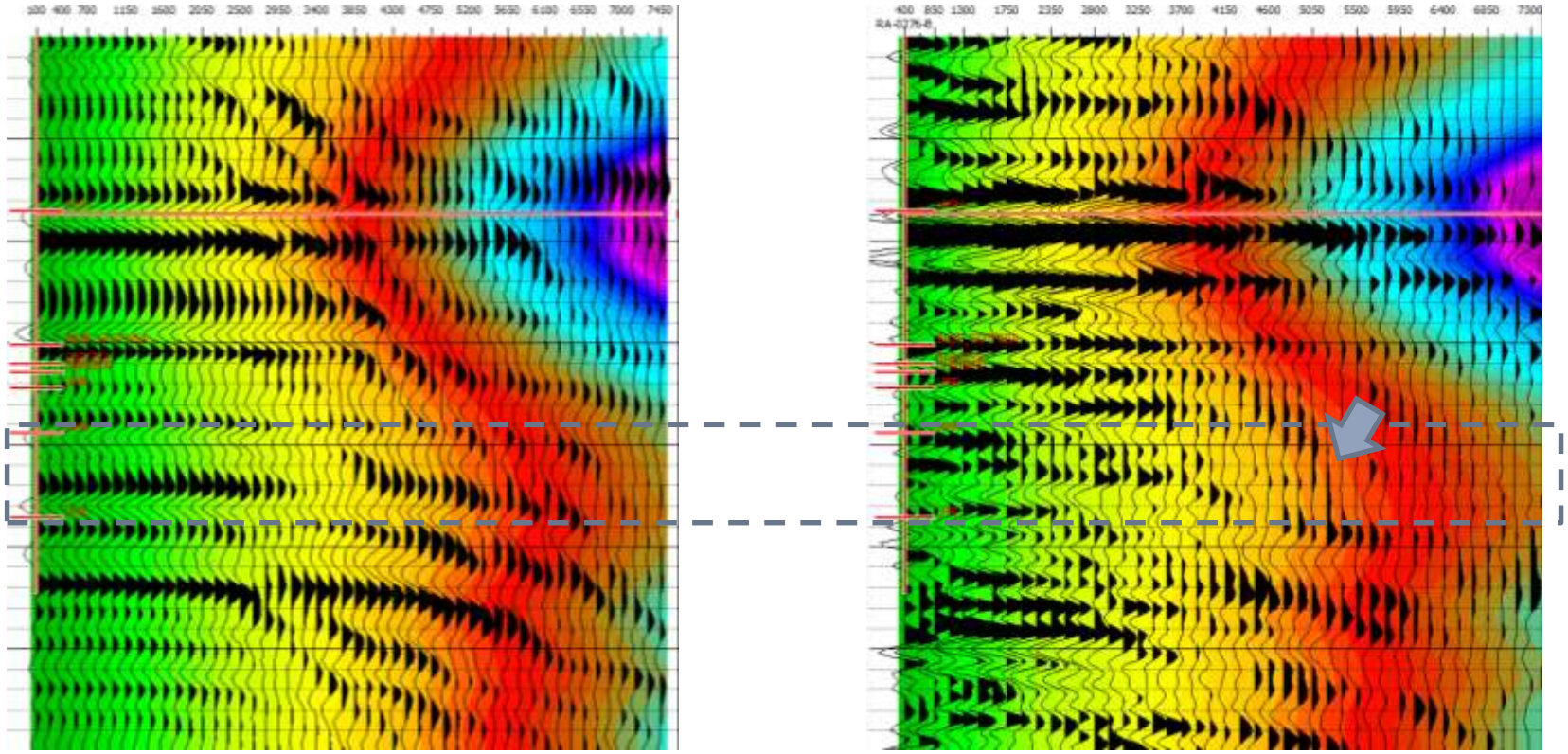
Elastic Reflectivity Model and Field Data

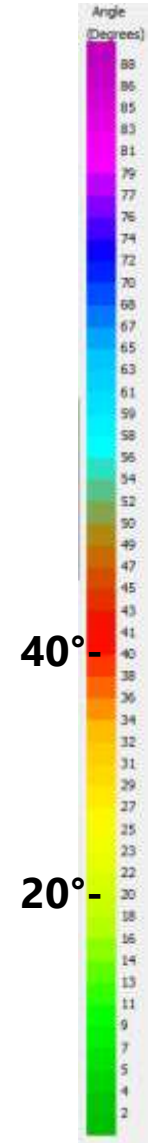
Primaries + multiples + converted waves

Surface seismic data

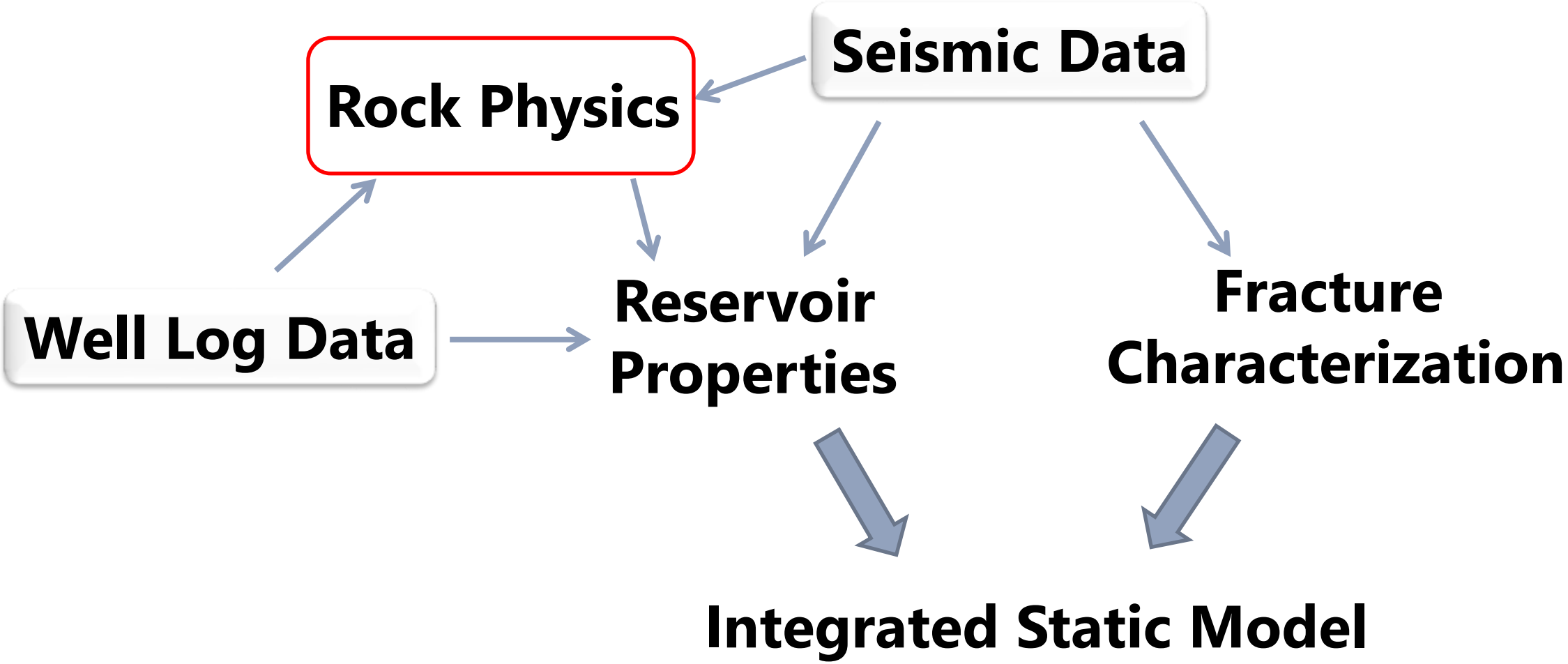
Hith

MMR



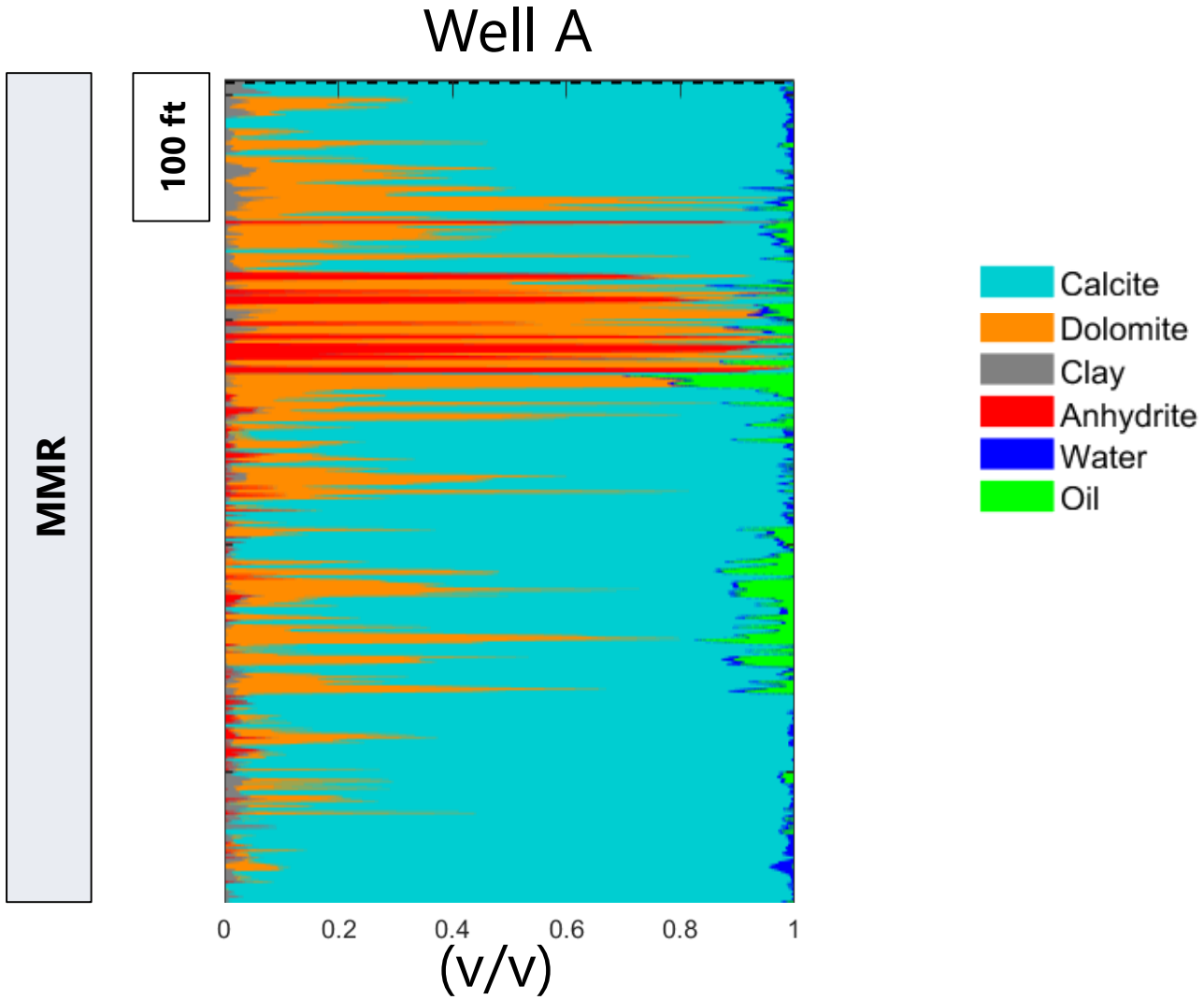


Reservoir Characterization



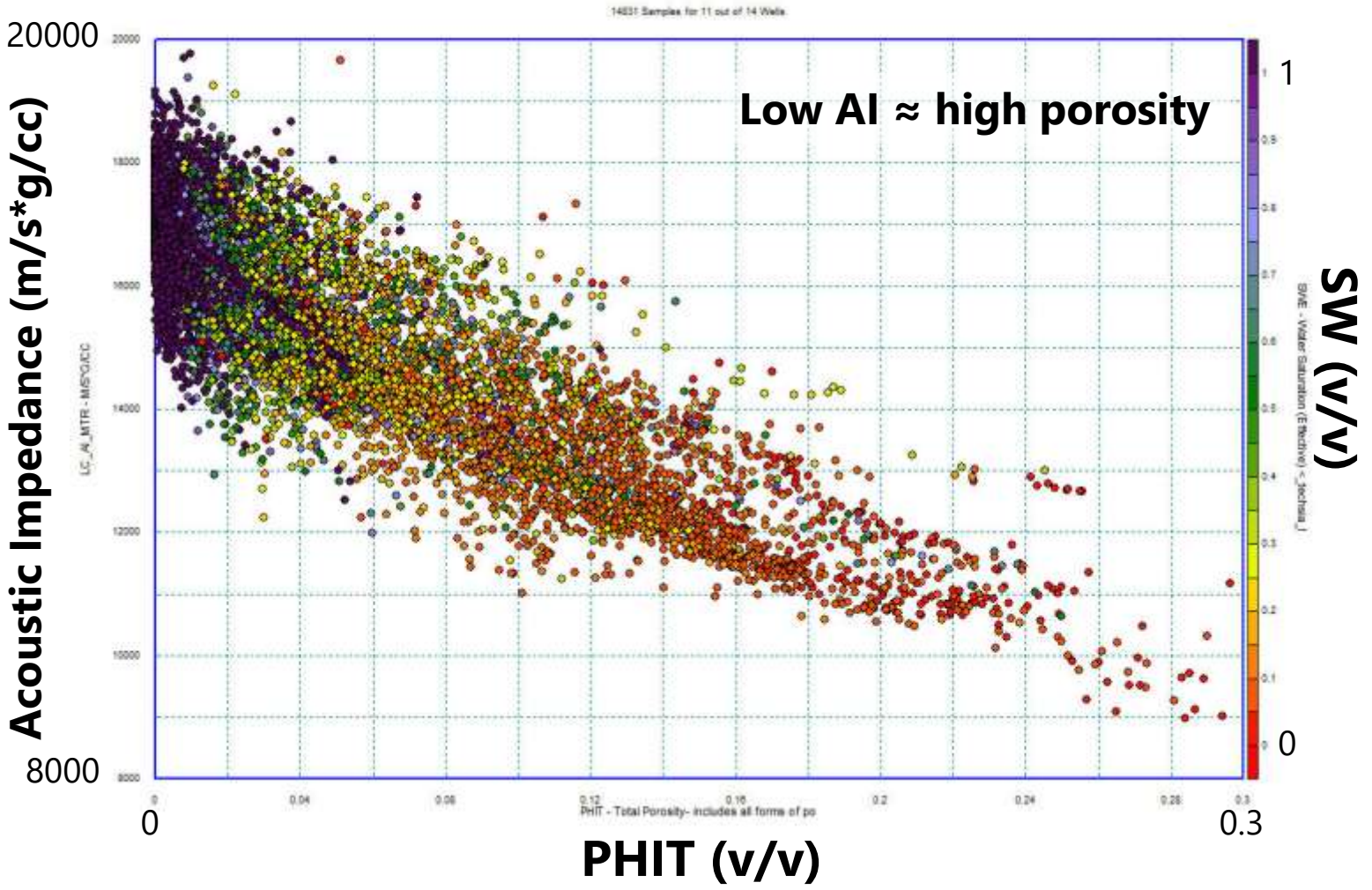
Multi-mineral Analysis

Petrophysical inversion from GR, RHOB, DTC, NPHI, resistivity logs



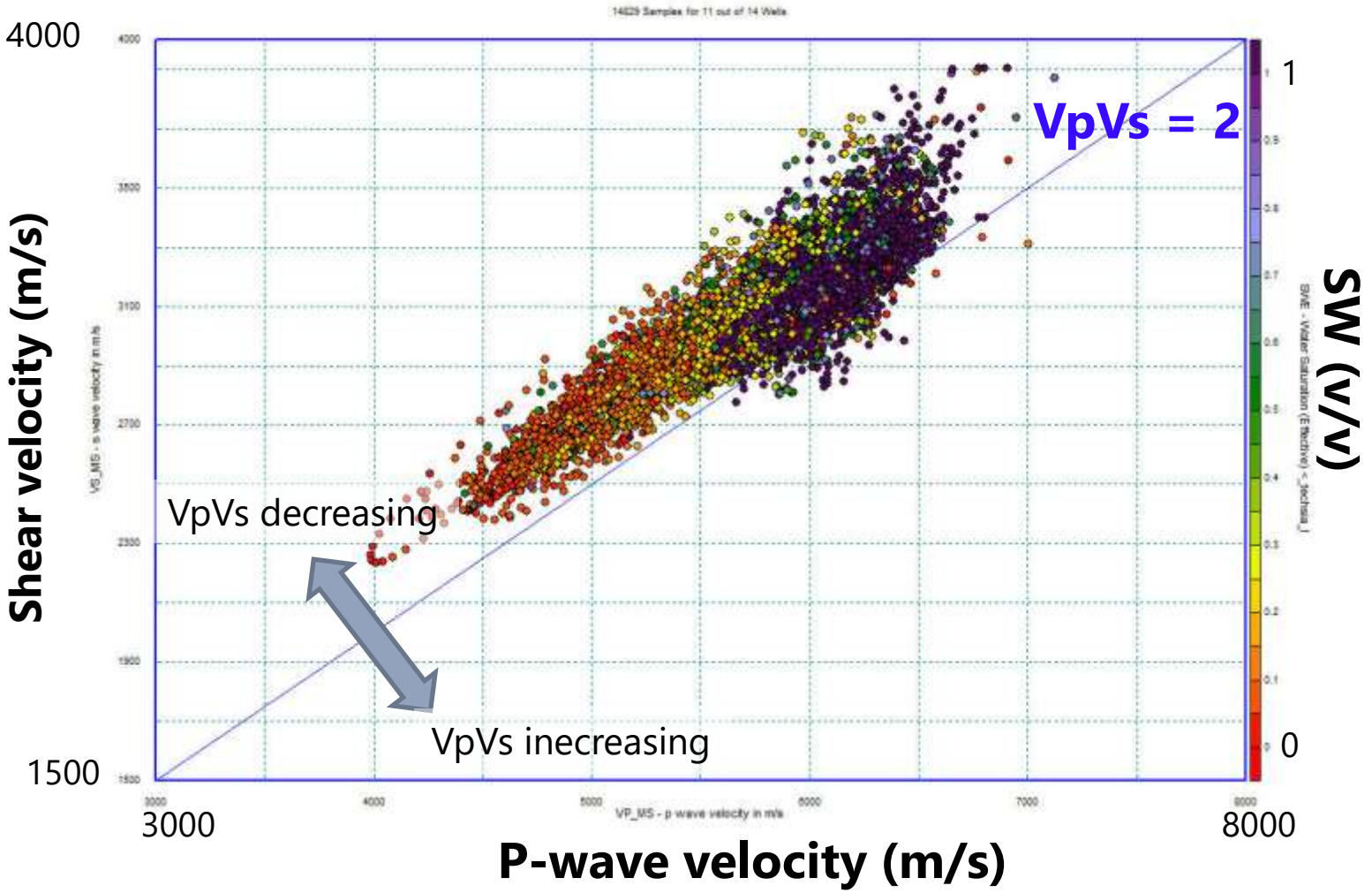
Acoustic Impedance vs. Total Porosity

Middle Marrat only; 11 wells combined



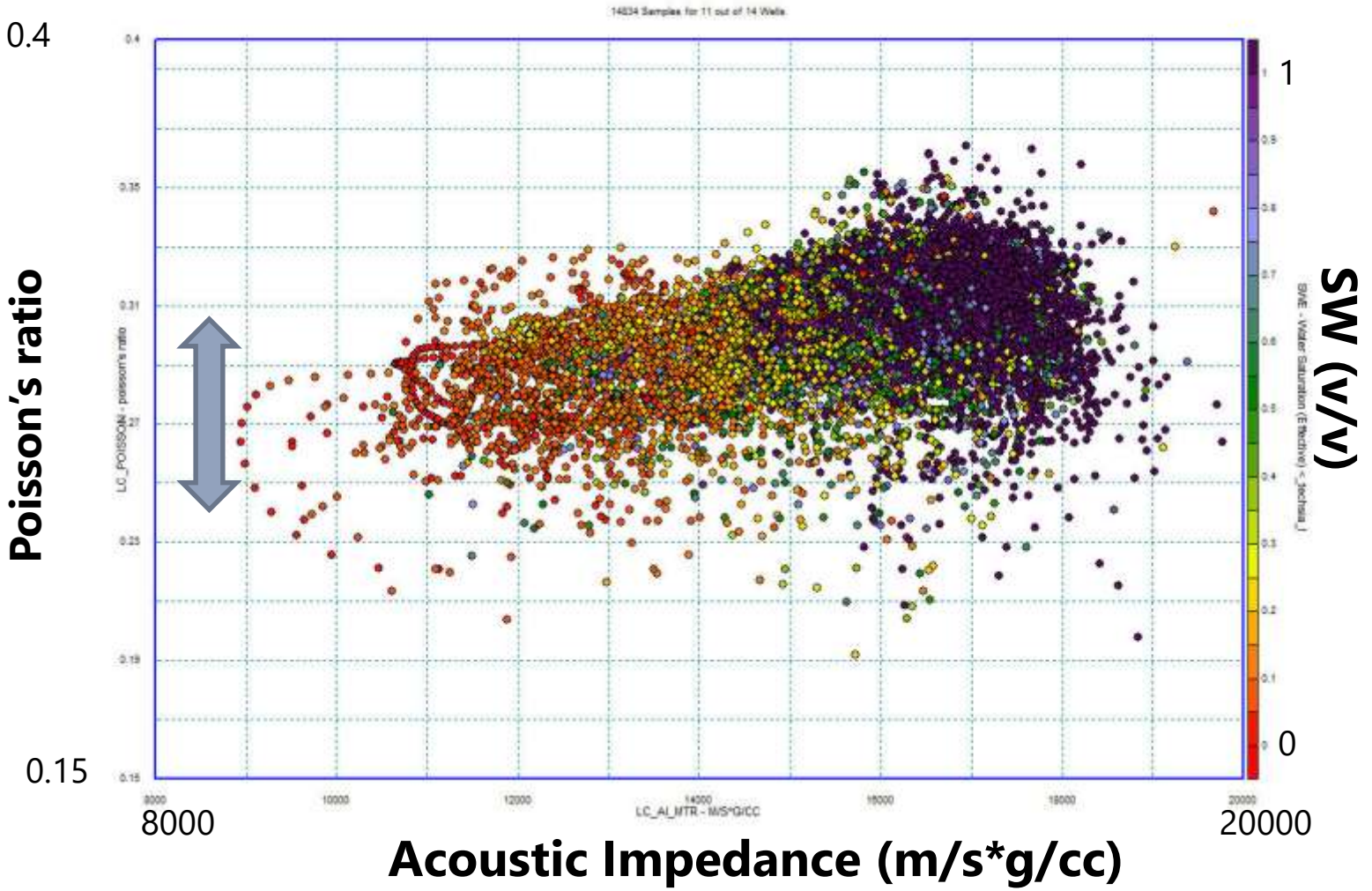
Compressional vs. Shear Velocity

Middle Marrat only; 11 wells combined



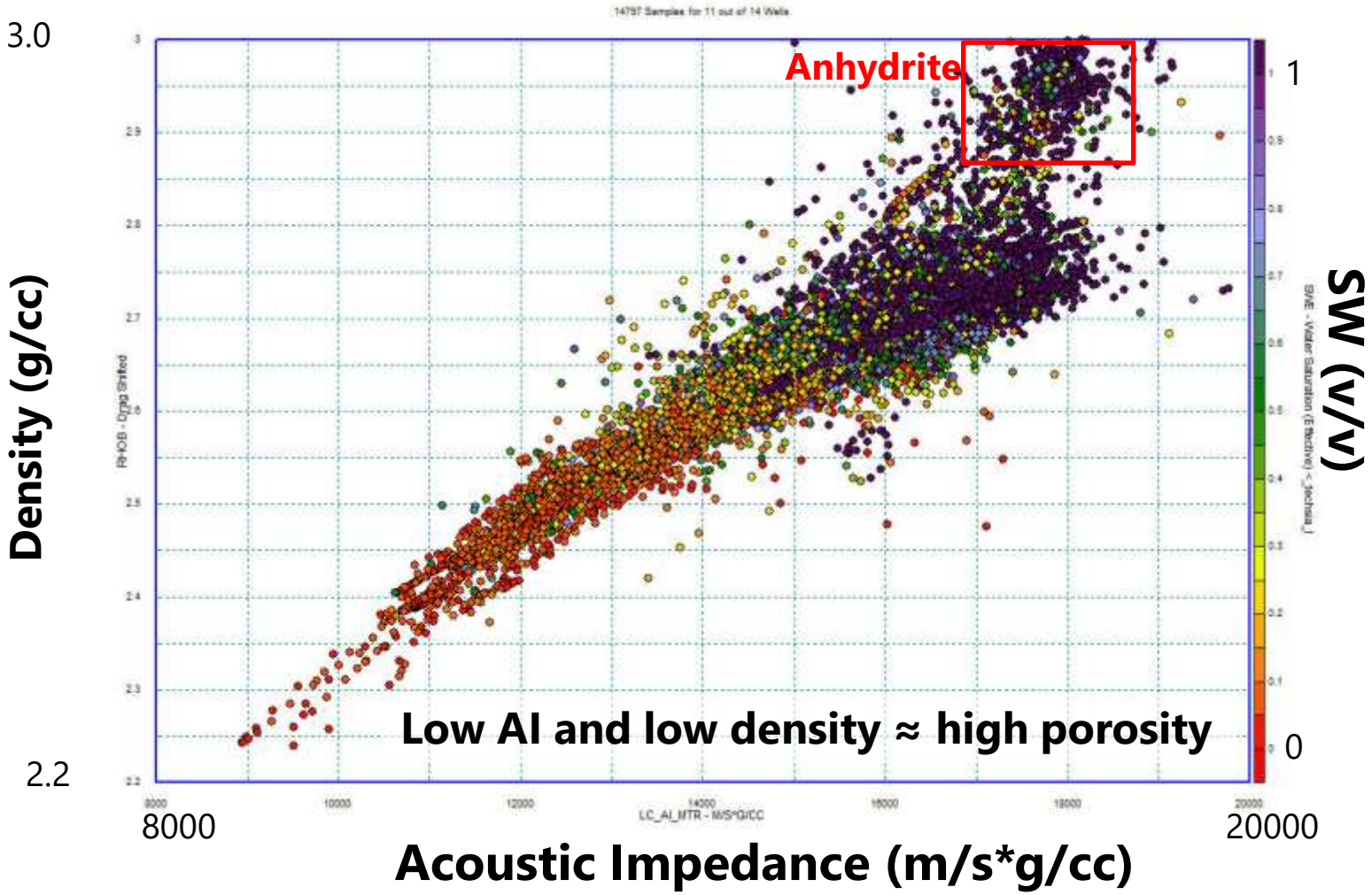
Acoustic Impedance vs. Poisson's Ratio

Middle Marrat only; 11 wells combined

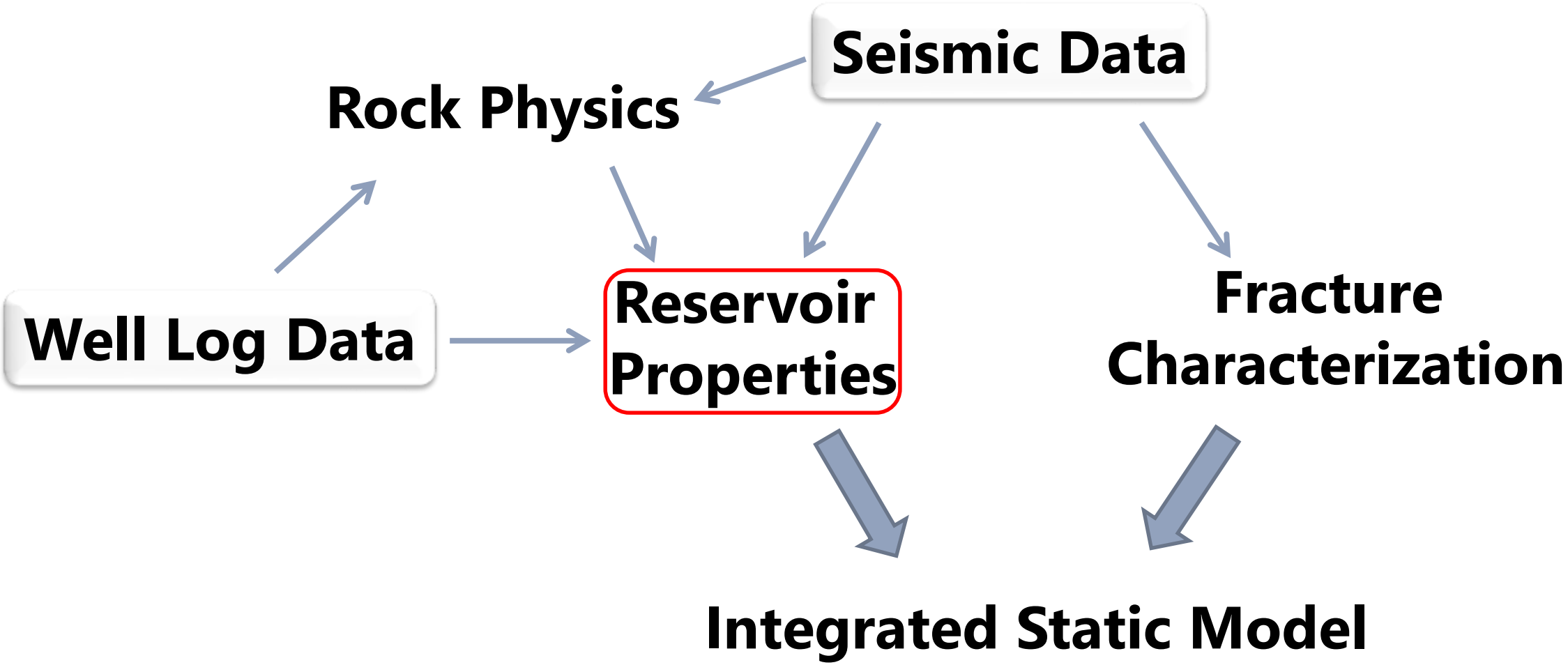


Acoustic Impedance vs. Density

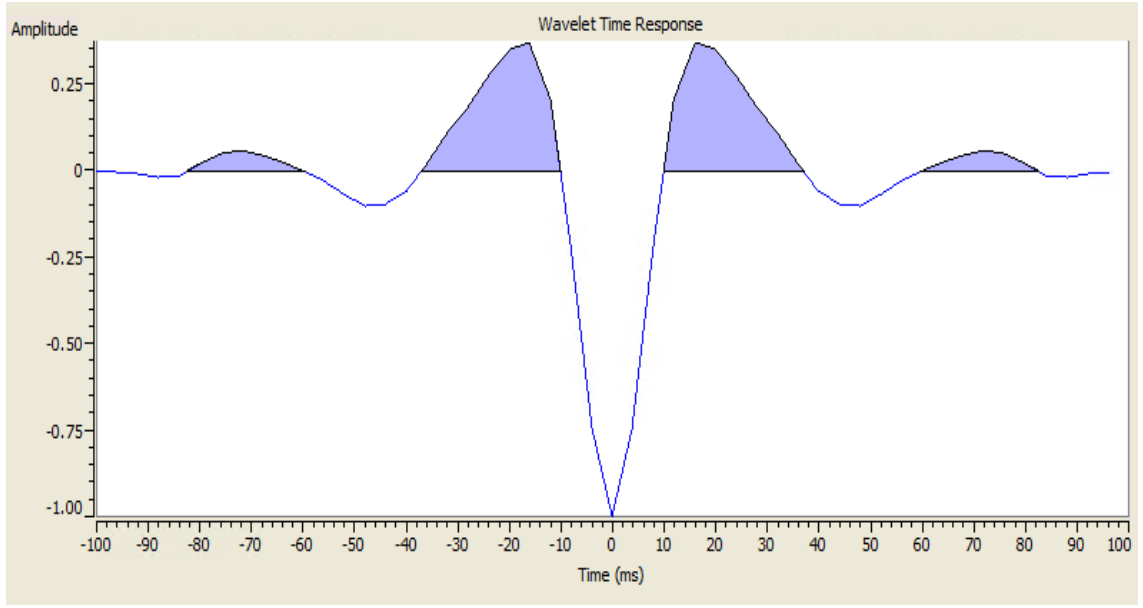
Middle Marrat only; 11 wells combined

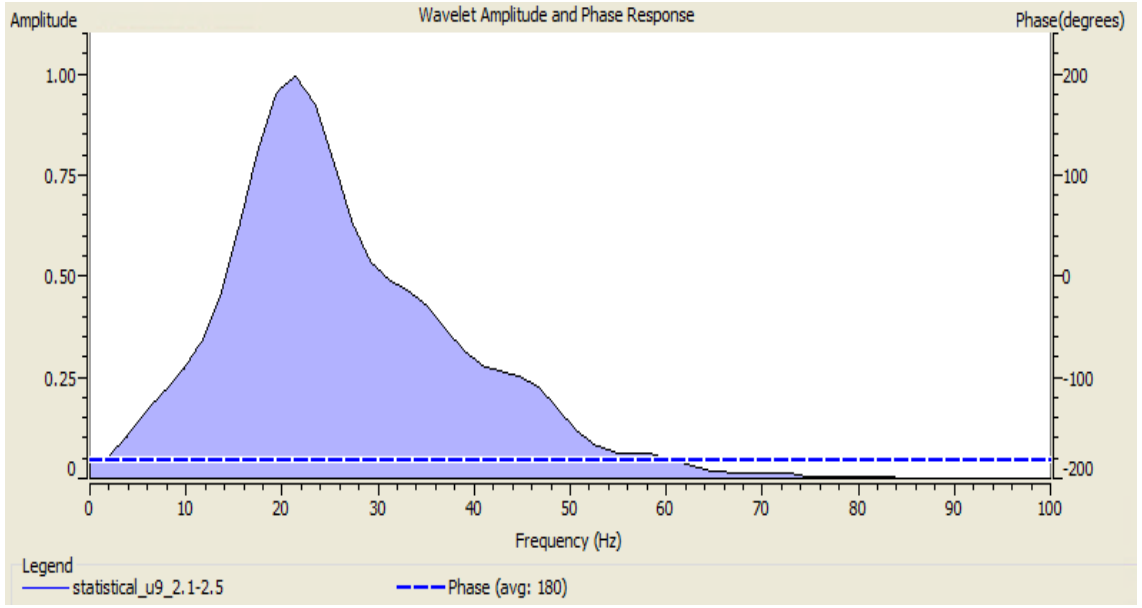


Reservoir Characterization



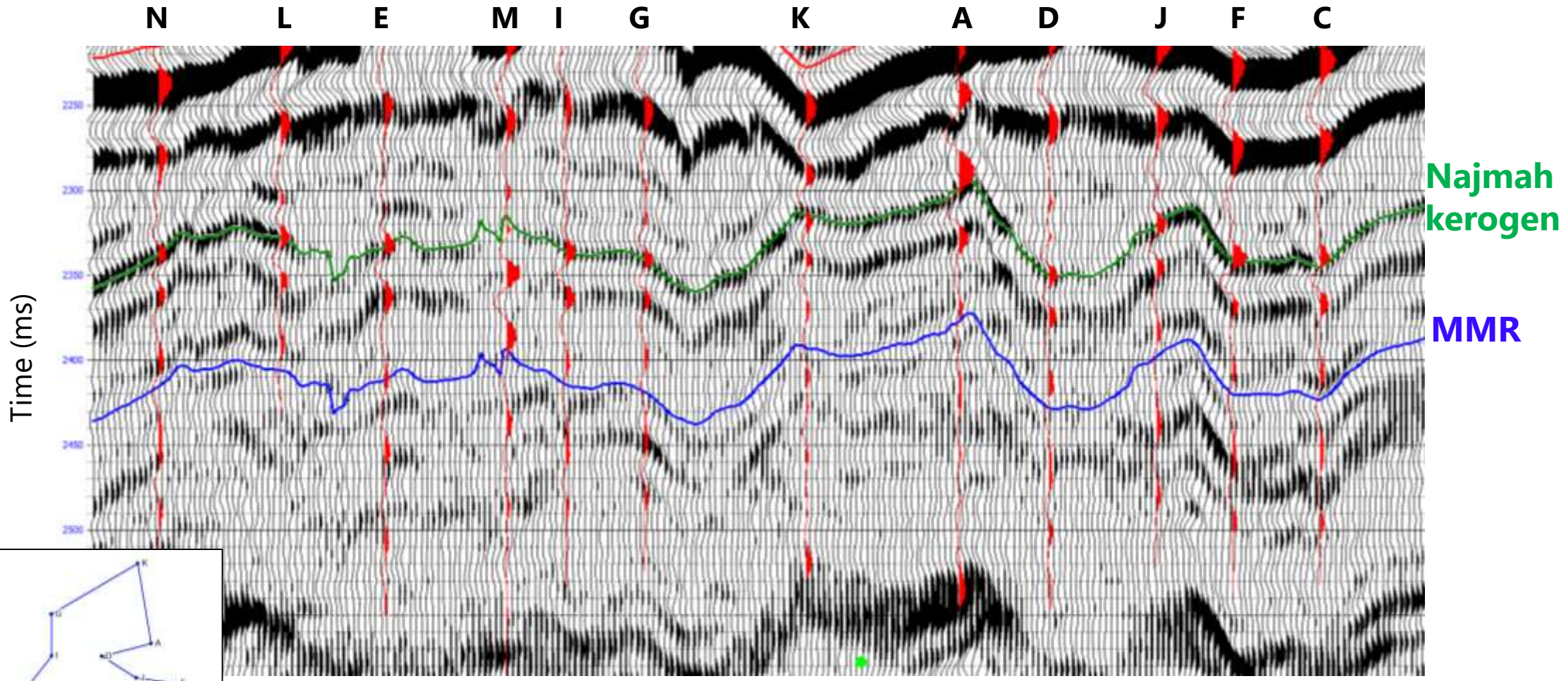
Wavelet





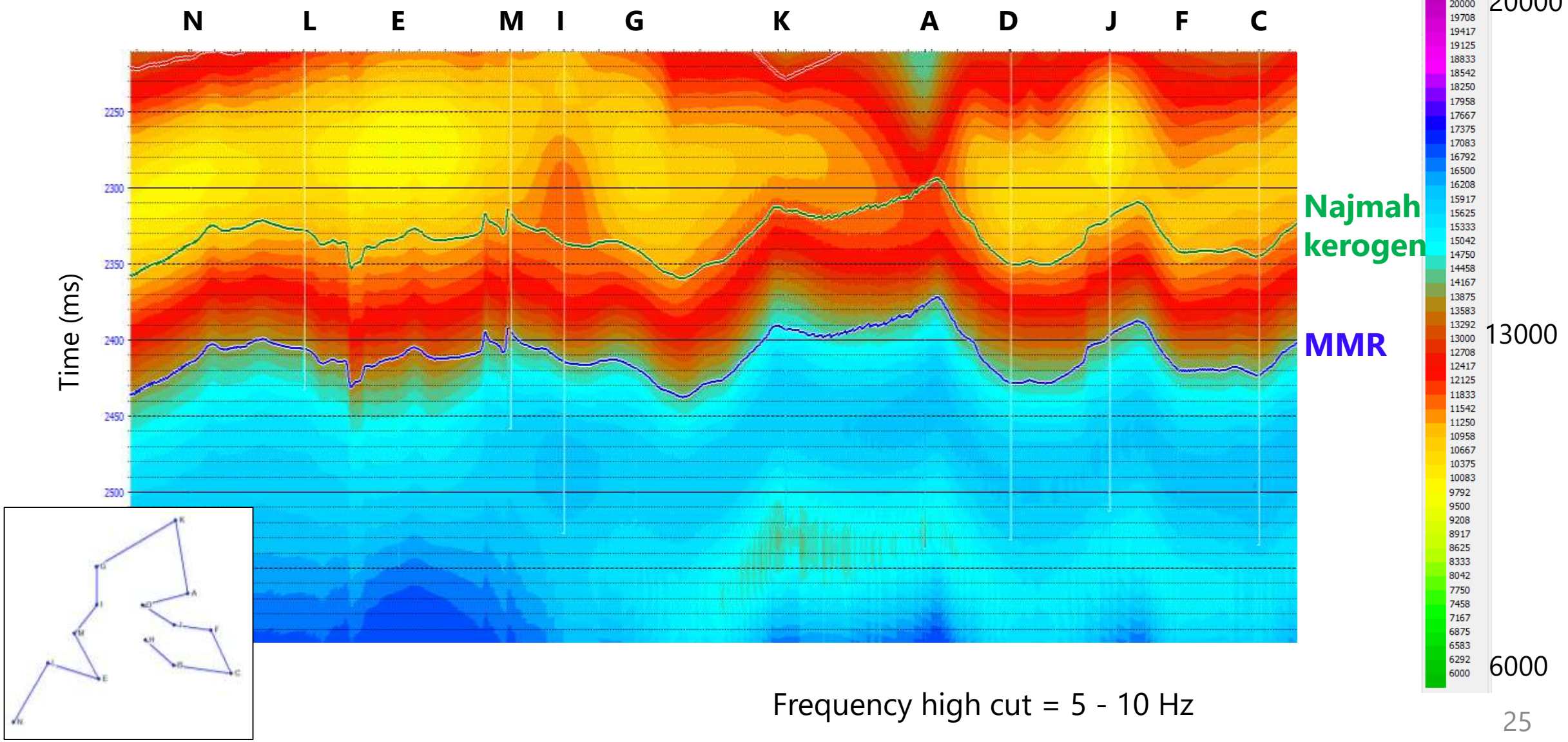
Statistical wavelet extracted from 2.3 – 2.6 s; phase rotated 180°

Seismic Arbitrary Line



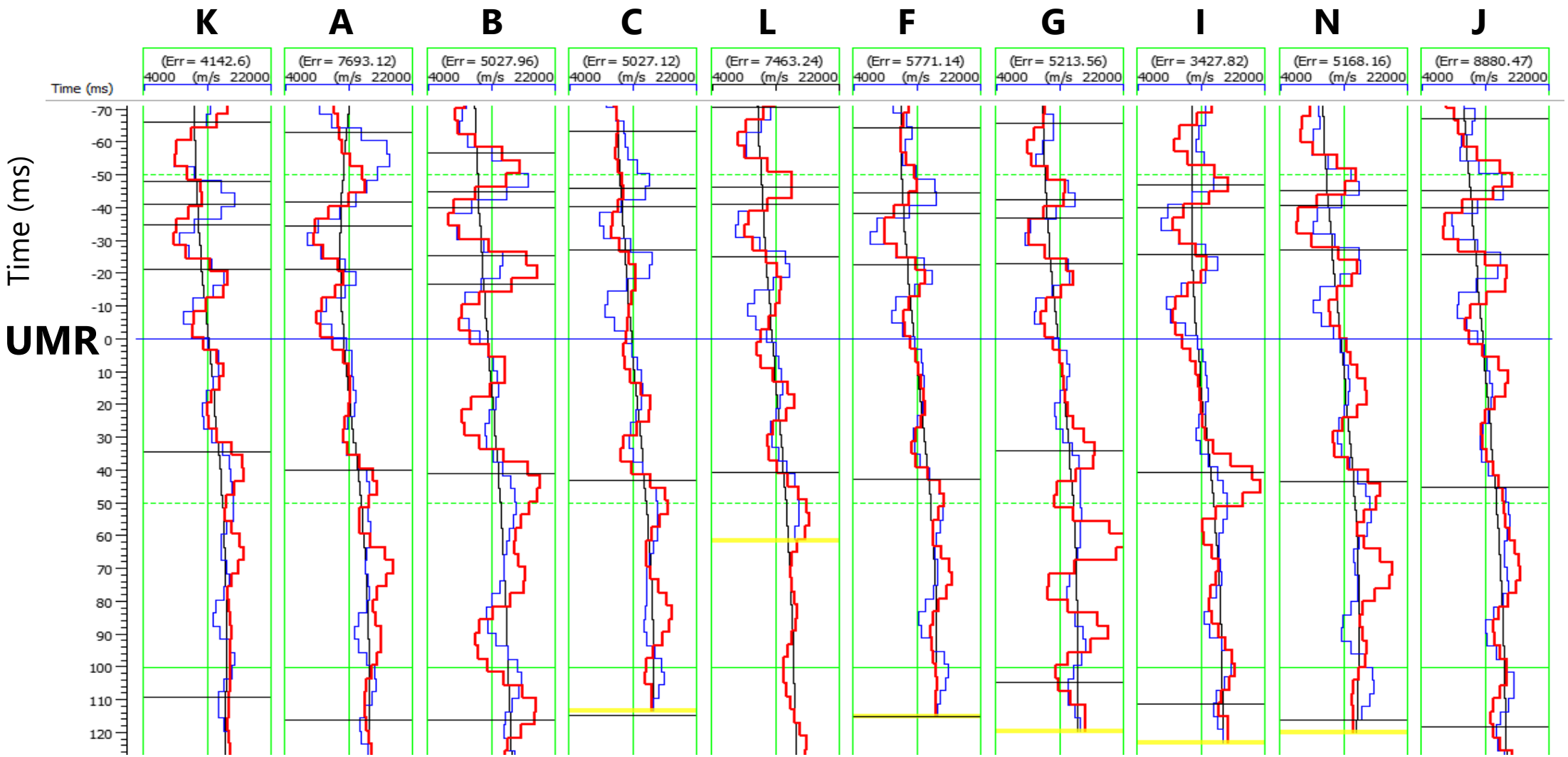
Red trace : synthetic trace

Acoustic Impedance Background Model



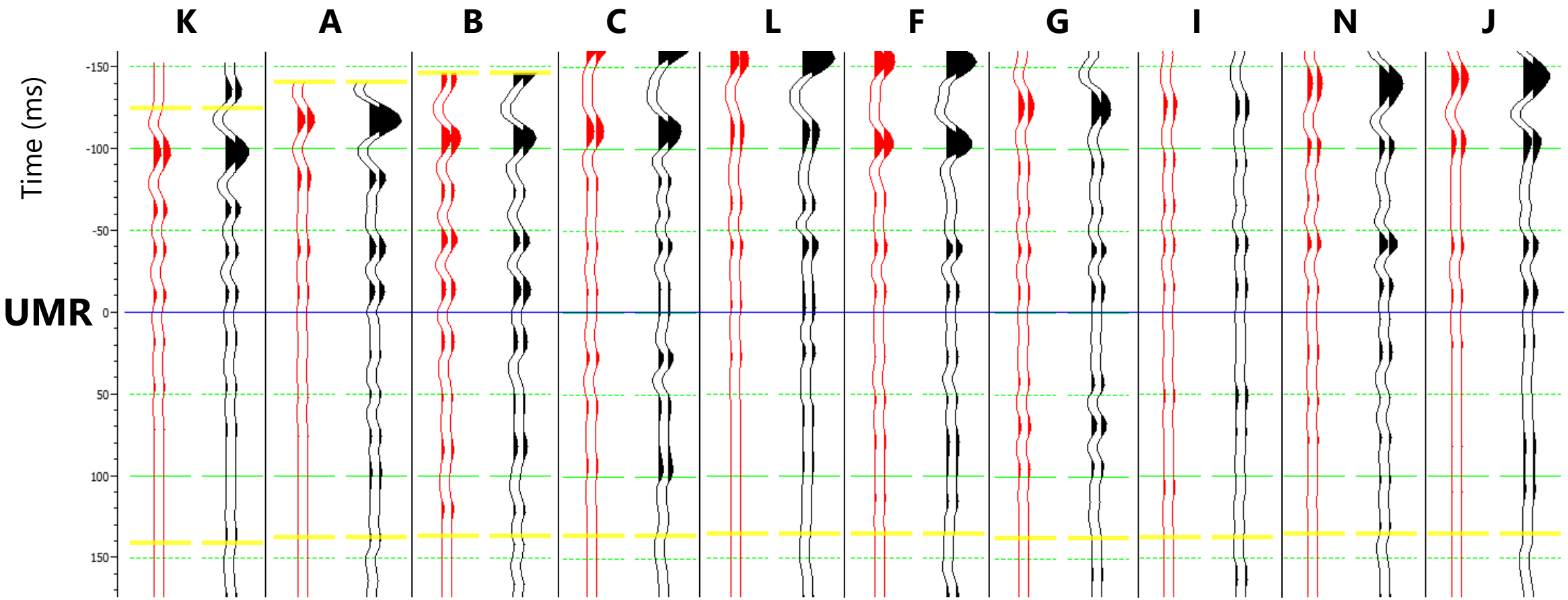
Frequency high cut = 5 - 10 Hz

Inversion Analysis

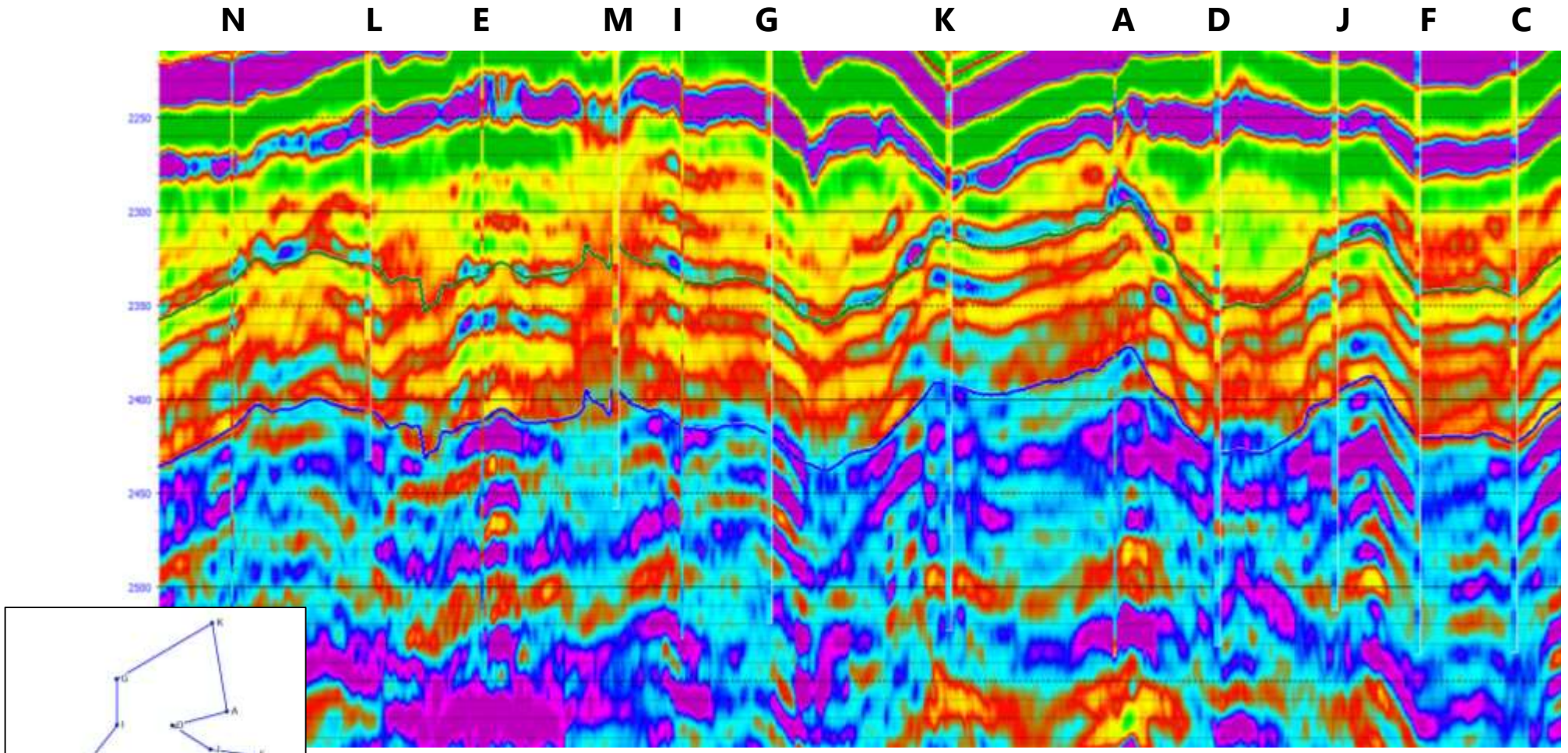


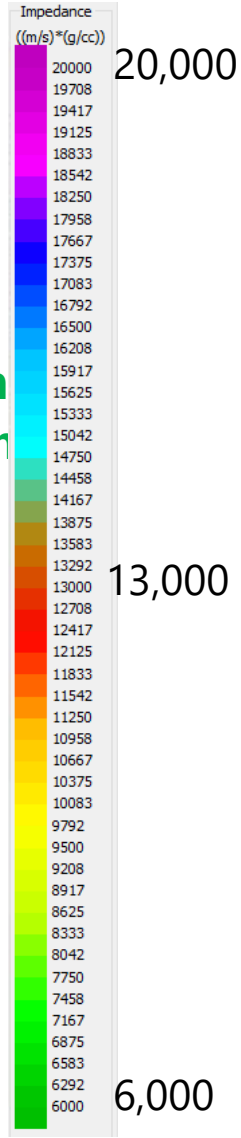
Background model Filtered well log Inversion

Inverted Prediction and Field Data Comparison



Acoustic Impedance Inversion





Summary

- Based on the 2D ray tracing model, the higher incident angle waves (> 40°) may never be able to reach the reservoir interval
- Multiple and converted waves also add challenges on the imaging of high angle of incidence
- Based on rock physics cross-plots, acoustic impedance and density are good indicators of the porous zone in middle Marrat
- The seismic inversion is dominated by the high amplitude of Gotnia and Najmah kerogen intervals. An inversion focused on Marrat interval will be needed in the future work

RESERVOIR CHARACTERIZATION PROJECT

New KOC Raudhatain Field Projects

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COLORADOSCHOOLOFMINES

Outline

- New KOC Dataset
- Project 1: Facies Inversion through Machine Learning
- Project 2: Multiple Attenuation

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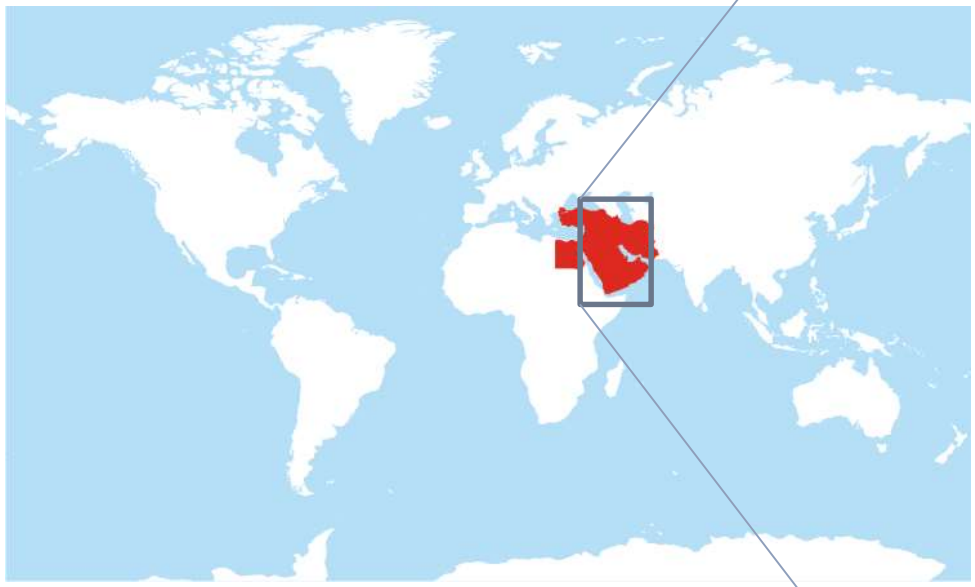
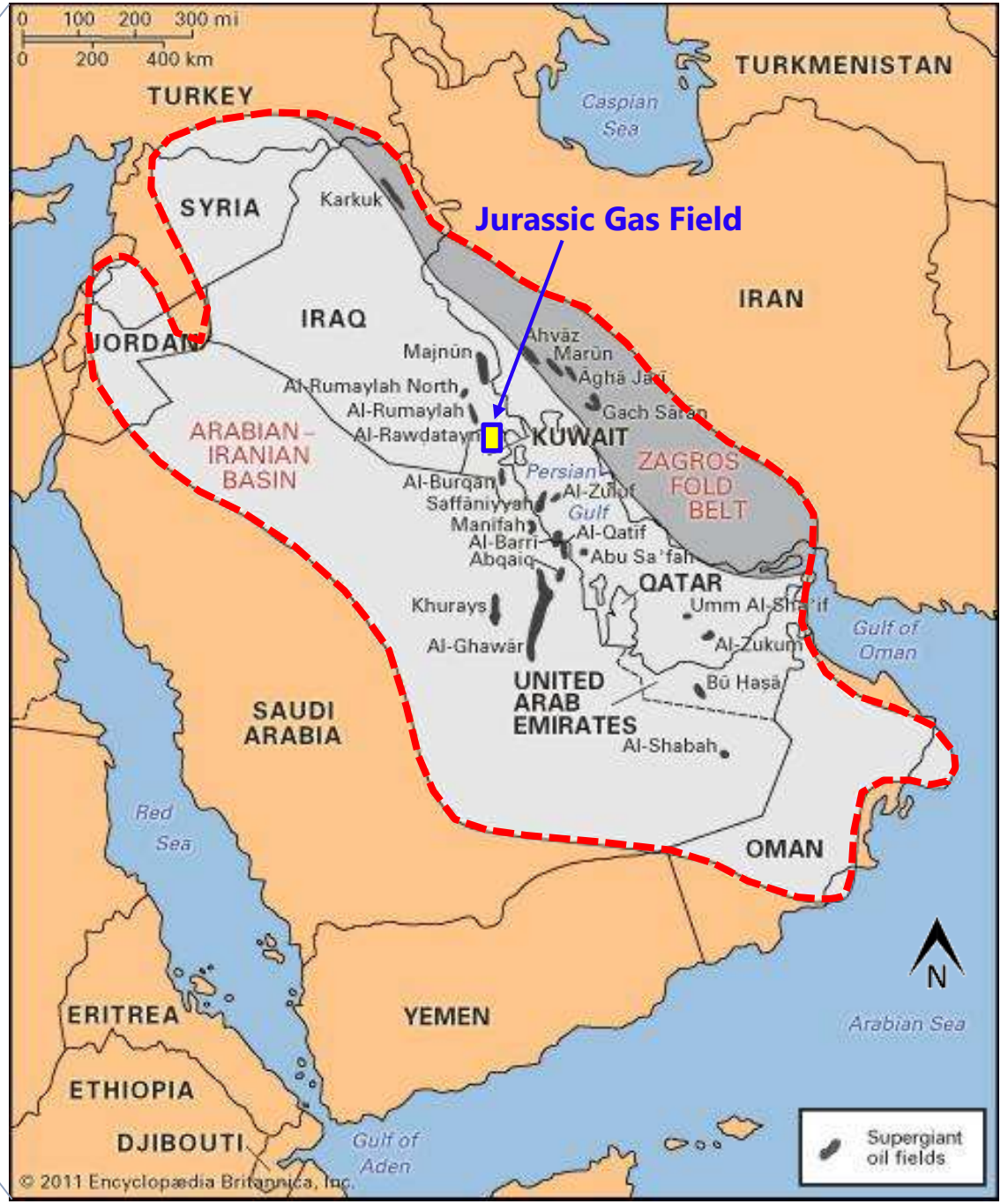
- Project 1: Facies Inversion through Machine Learning
- Project 2: Multiple Attenuation

Location



Source: http://www.freeworldmaps.net

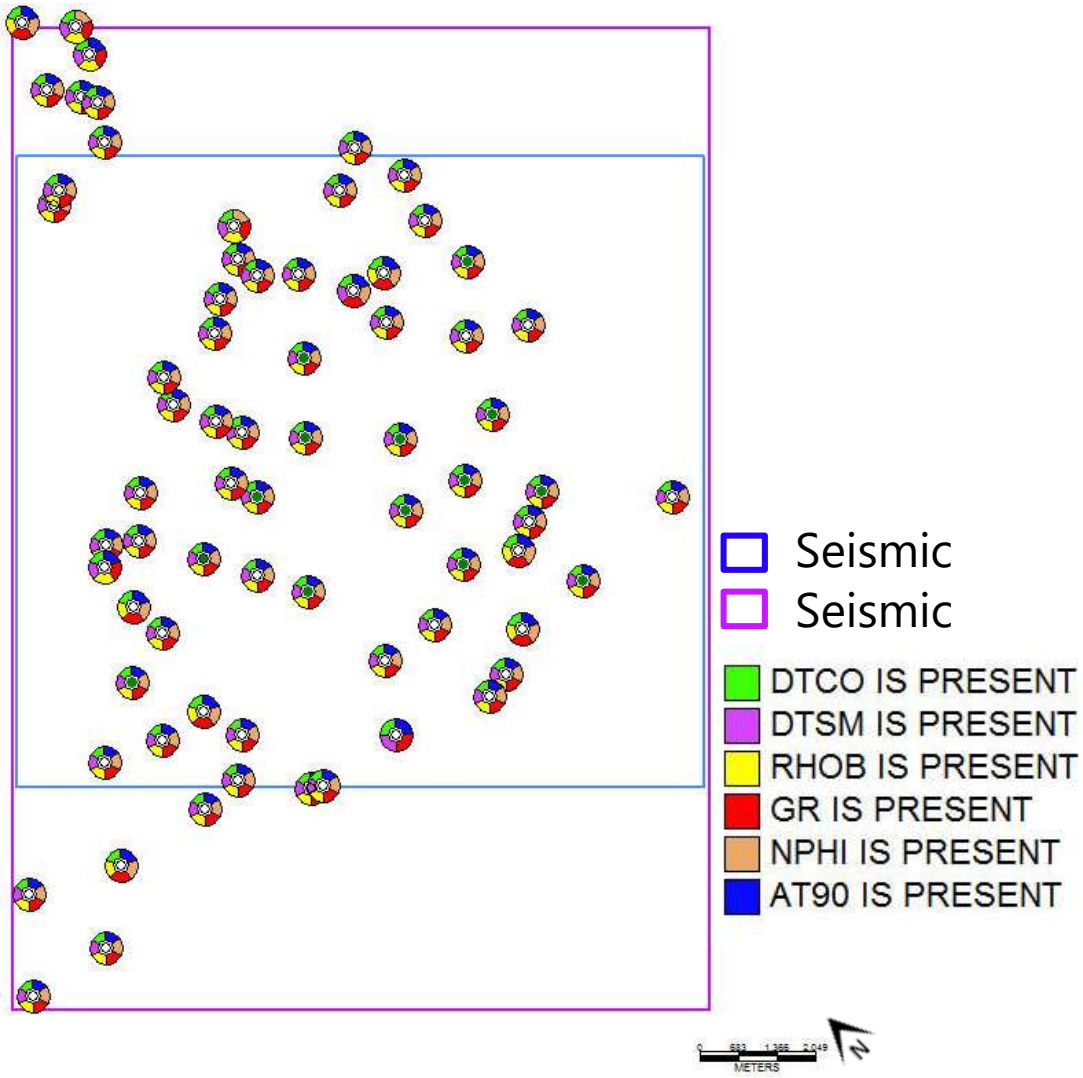


RCP
In pursuit of new ideas

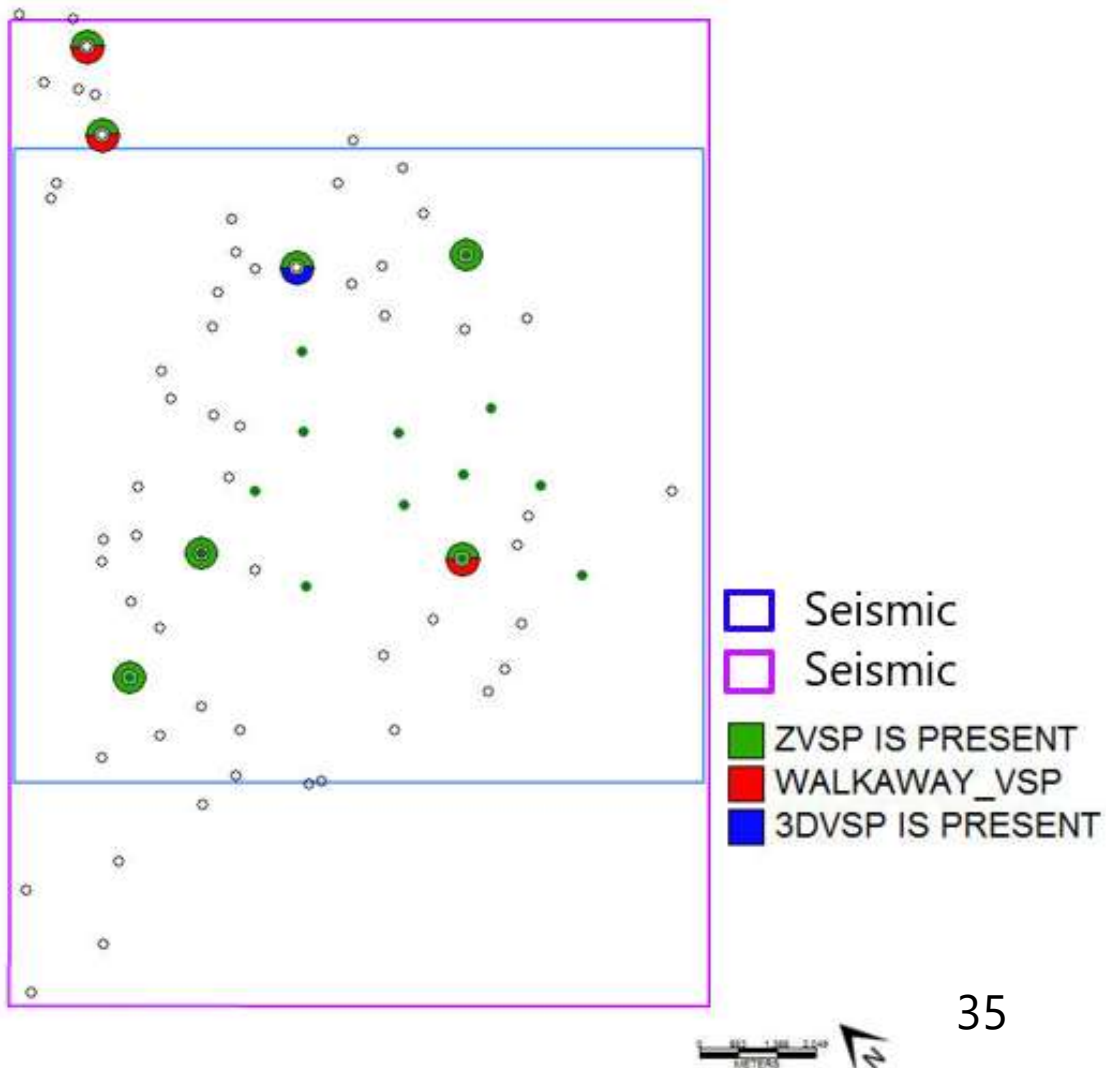
New Data

RCP
In pursuit of new ideas

Well logs



VSPs



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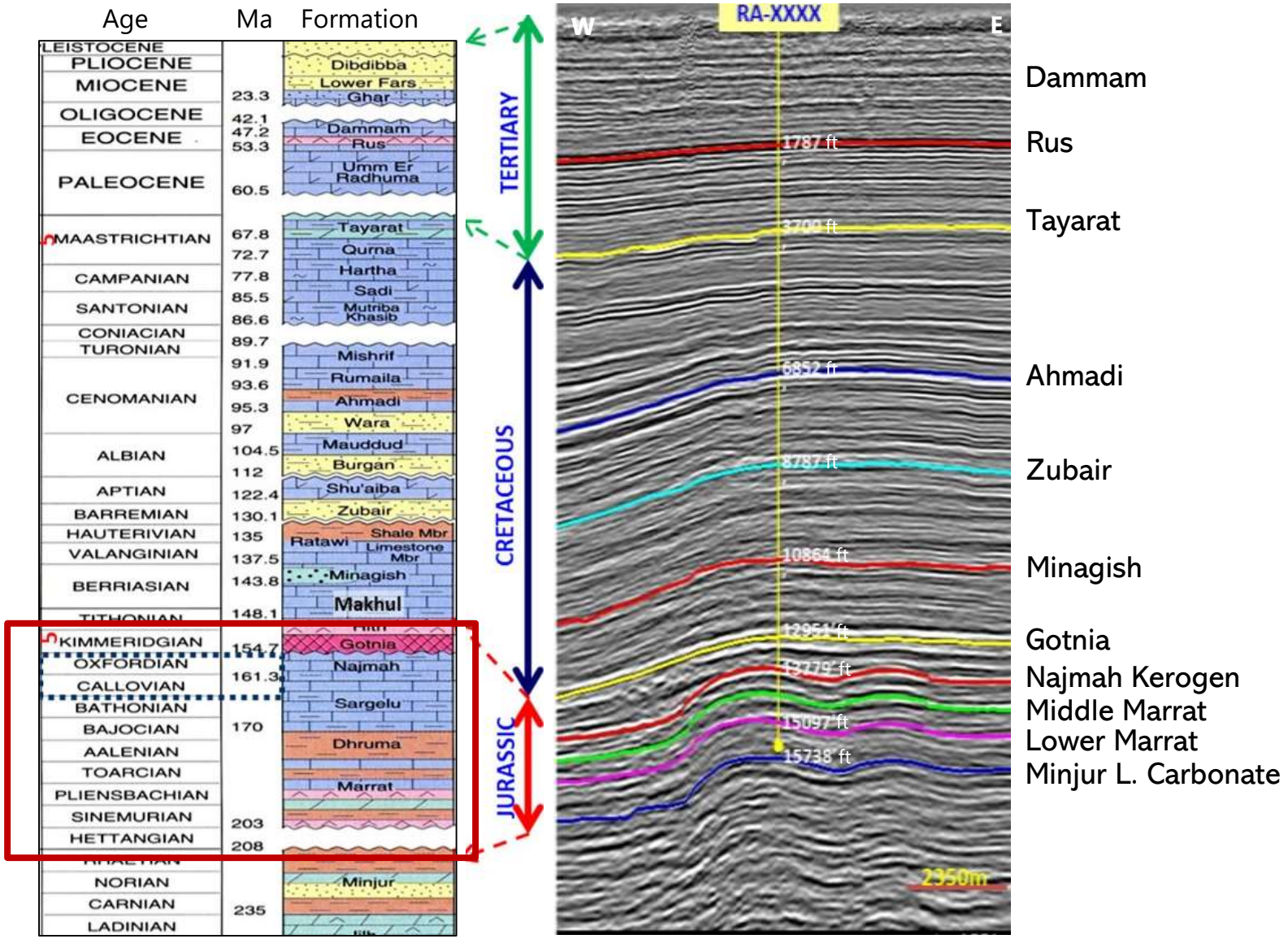
- New KOC Dataset
- Project 1: Facies Inversion through Machine Learning
- Project 2: Multiple Attenuation

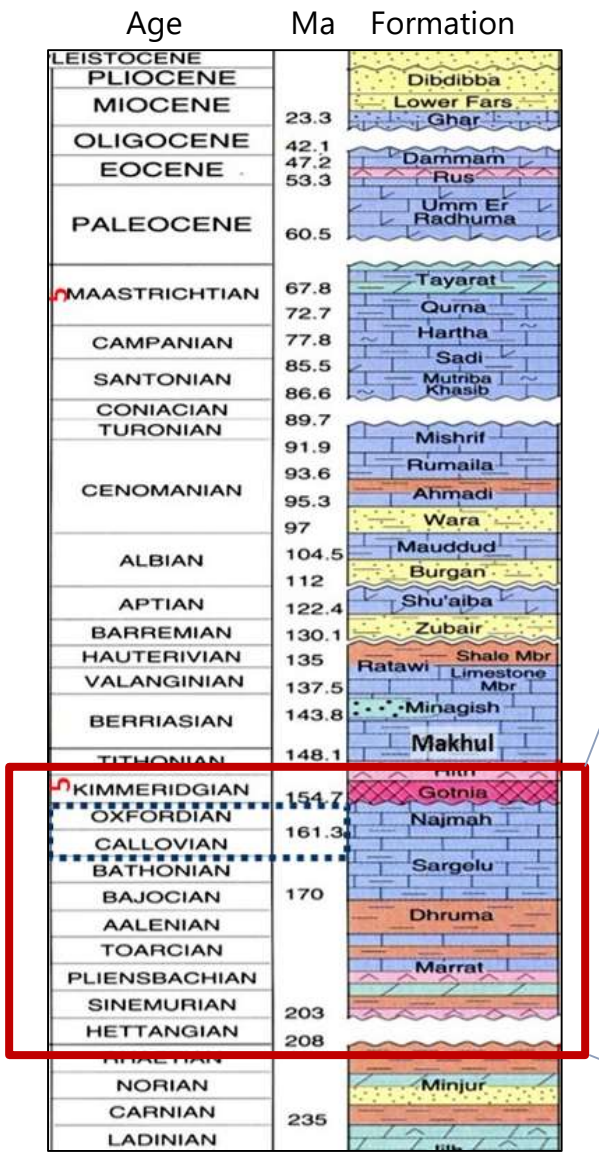
Generalized Stratigraphy and Seismic Section



Jurassic Reservoirs

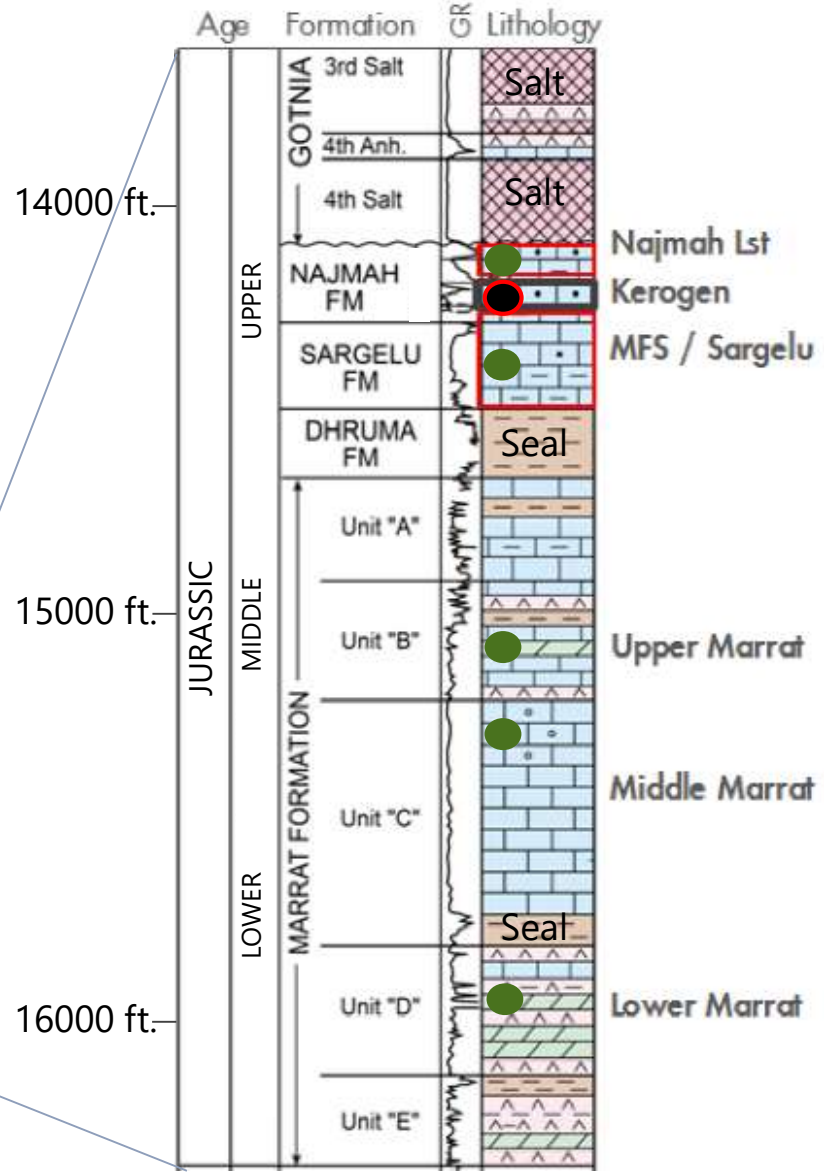
Source: KOC

Generalized Stratigraphy and Seismic Section



Source: KOC

Jurassic Reservoirs



Reservoir
Source rock

Motivation: Improved Resolution in North Kuwait

RCP
In pursuit of new ideas

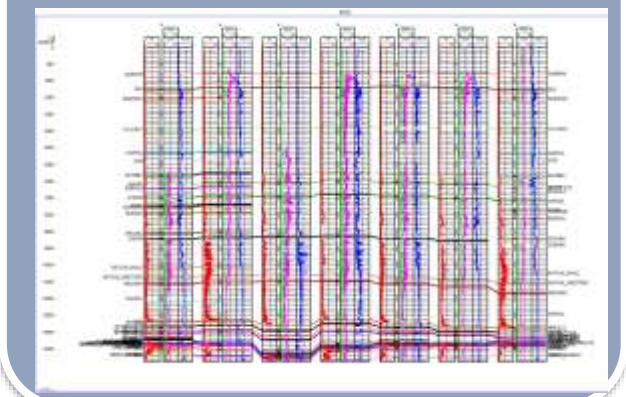
- Seismic resolution at depths
  - Identify and map the internal facies variation within Gotnia and Najmah and propagation of Facies in 3D using ML
  - Conventional inversion workflows
- Reservoir characterization
  - Better understanding of depositional setting, fractures, and facies
  - Facies variation within highly pressurized HP/HT overburden (Salt-Anhydrite) with limestone stringers

Objective

- Develop Machine Learning facies inversion workflow for mapping of reservoirs

Step 1

Apply ML in well logs for facies inversion



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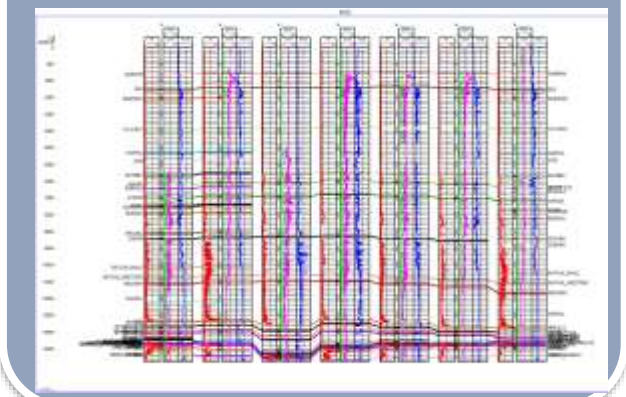
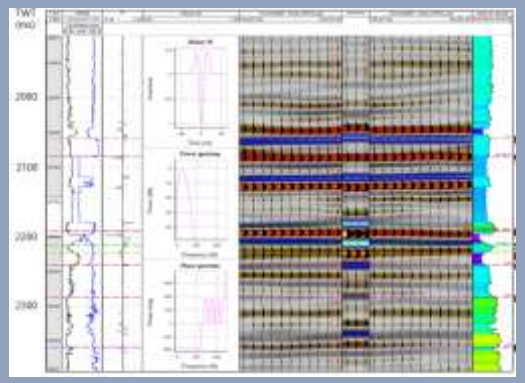


Step 2

Apply ML on seismic trace surrounding each well as a new feature



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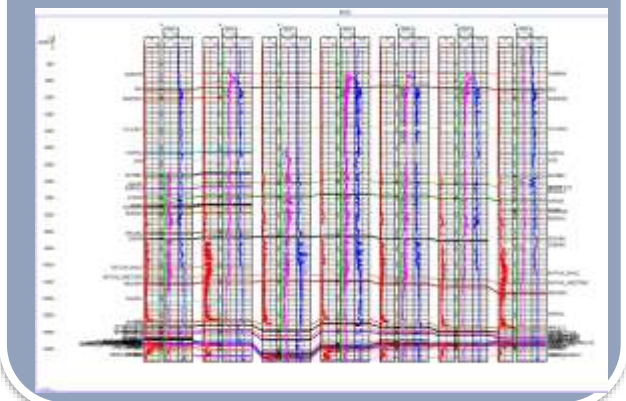

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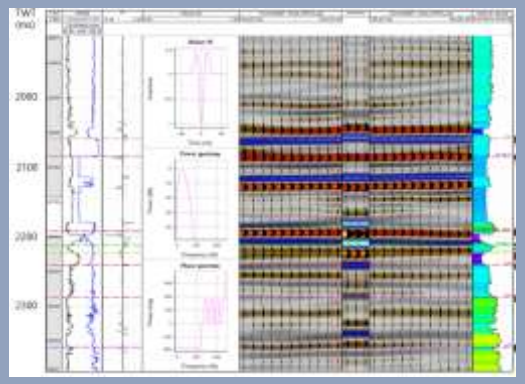
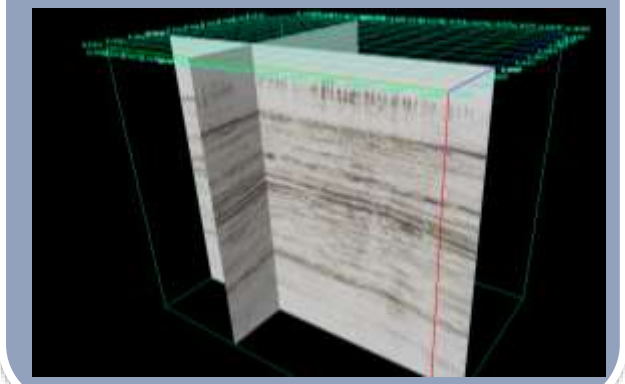


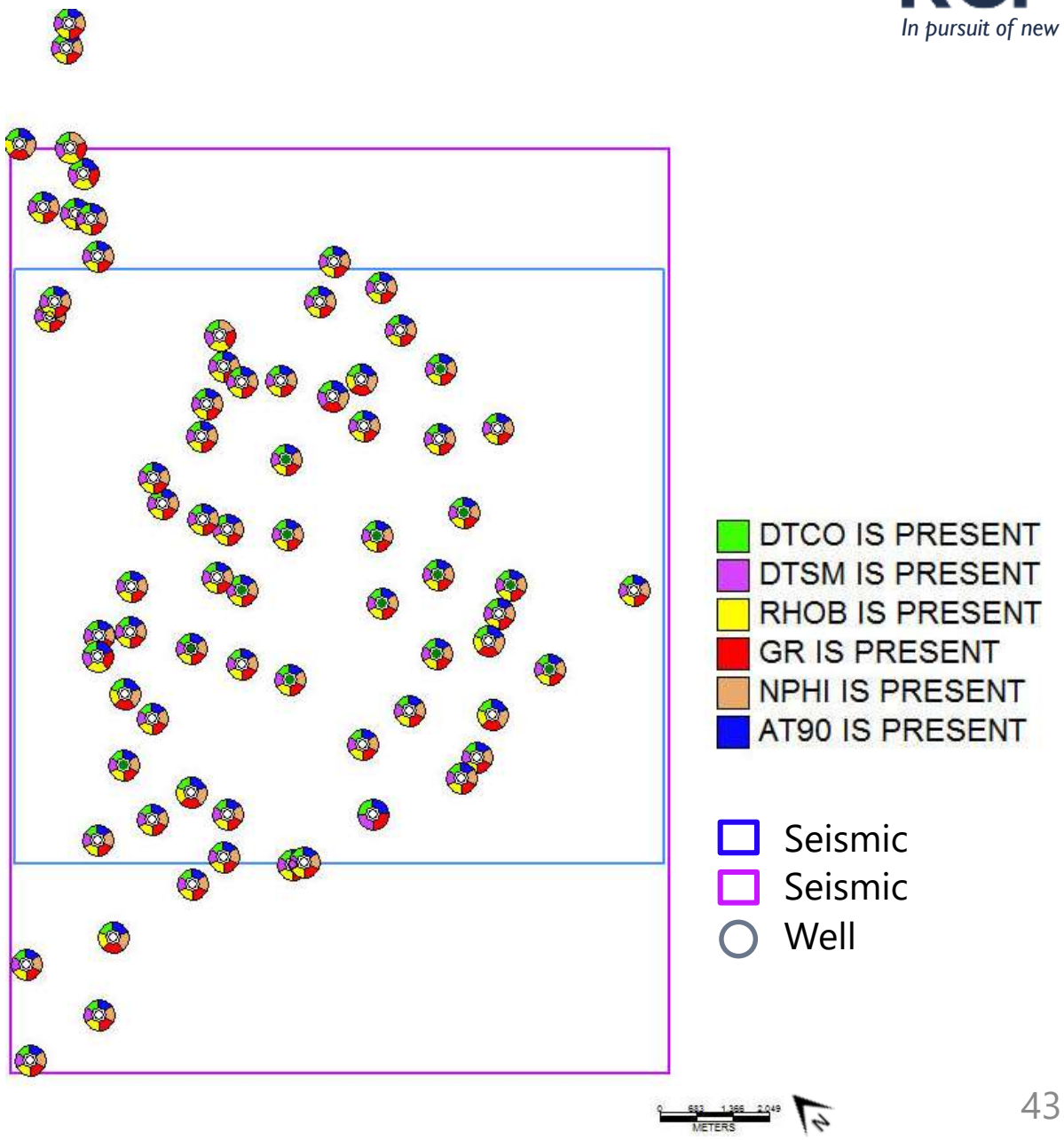
Step 3

Utilize final ML facies inversion algorithm for entire seismic volume



Well Log Dataset

- Total of 76 wells



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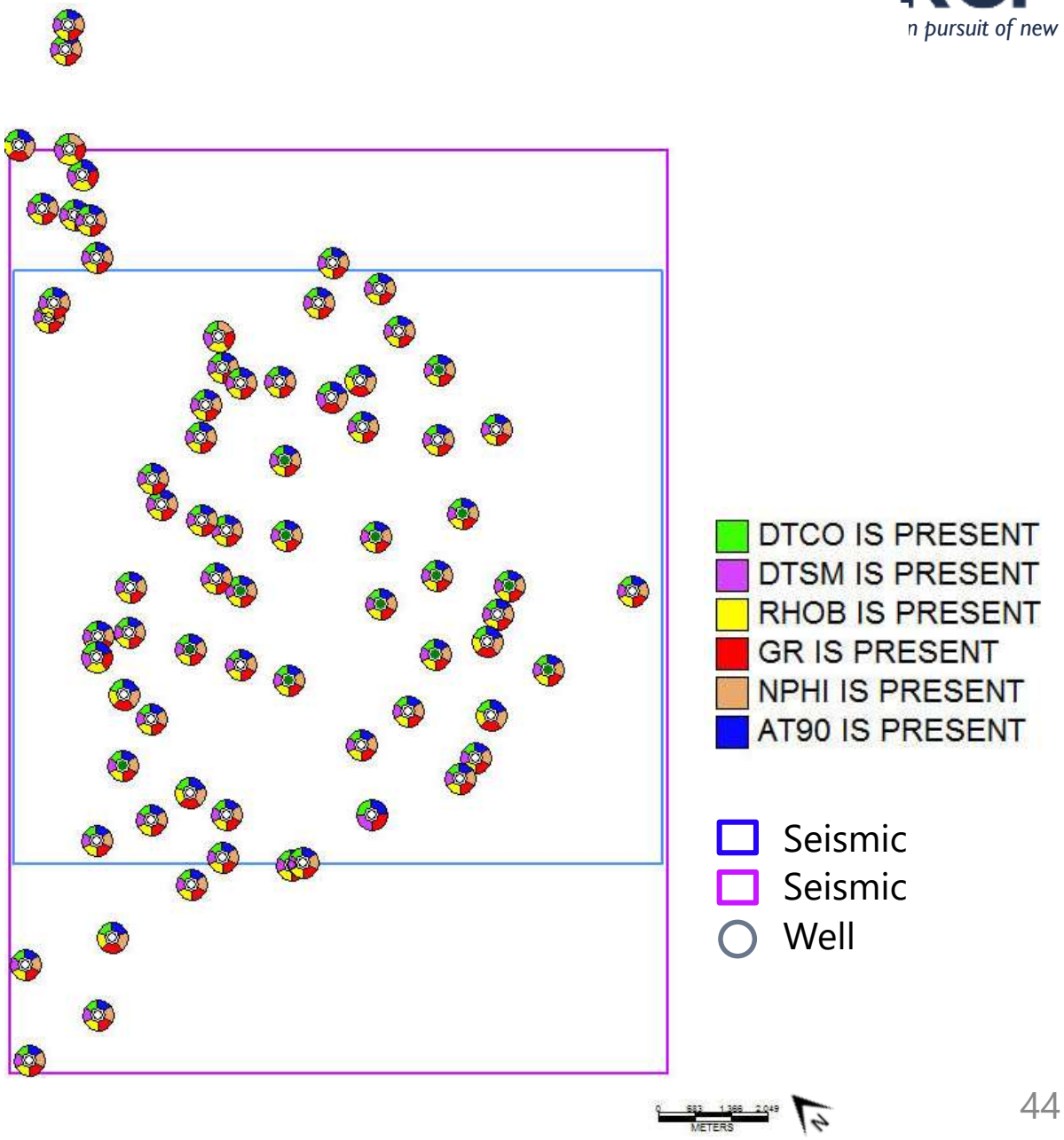
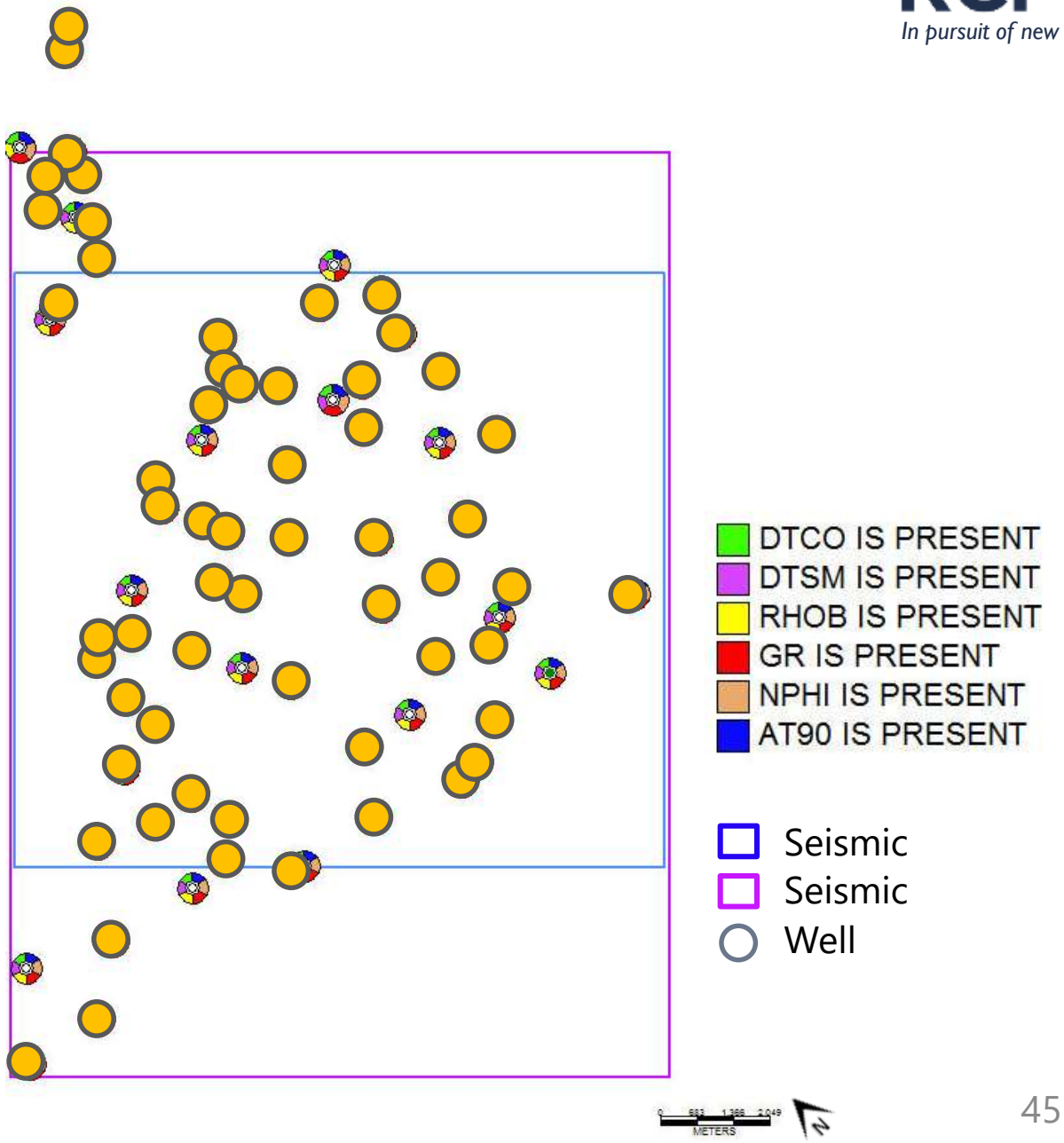


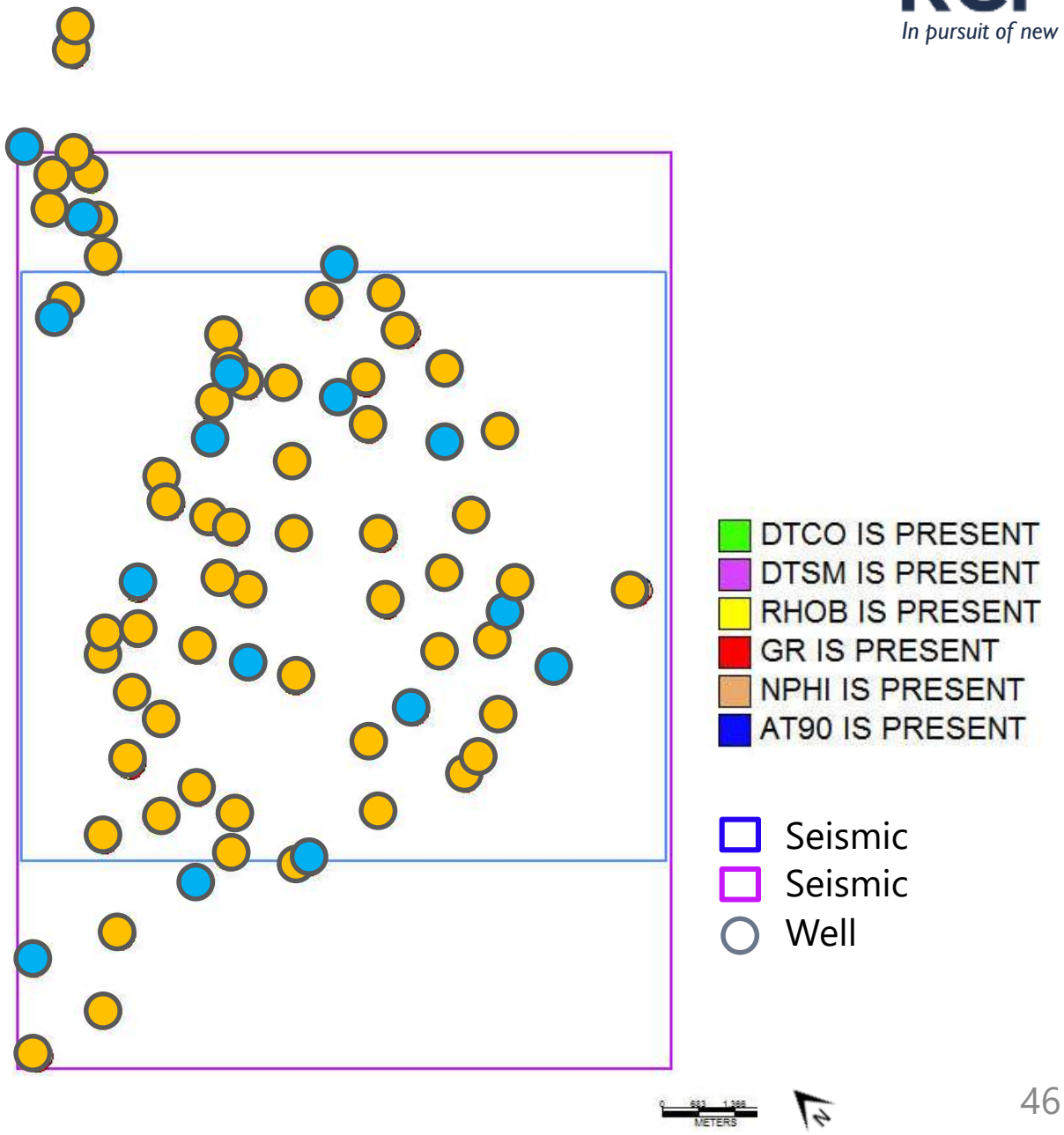
Well Log Dataset

- Total of 76 wells
  - 60 Training Well (80%)



Well Log Dataset

- Total of 76 wells
  - 60 Training Well (80%)
  - 16 Blind Test Well (20%)



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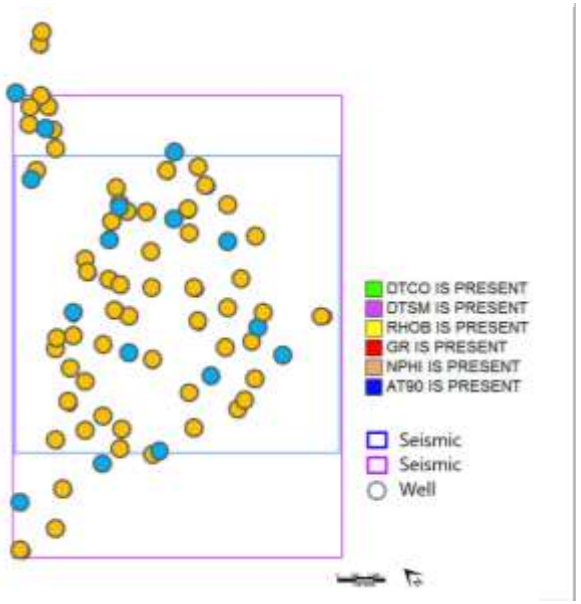

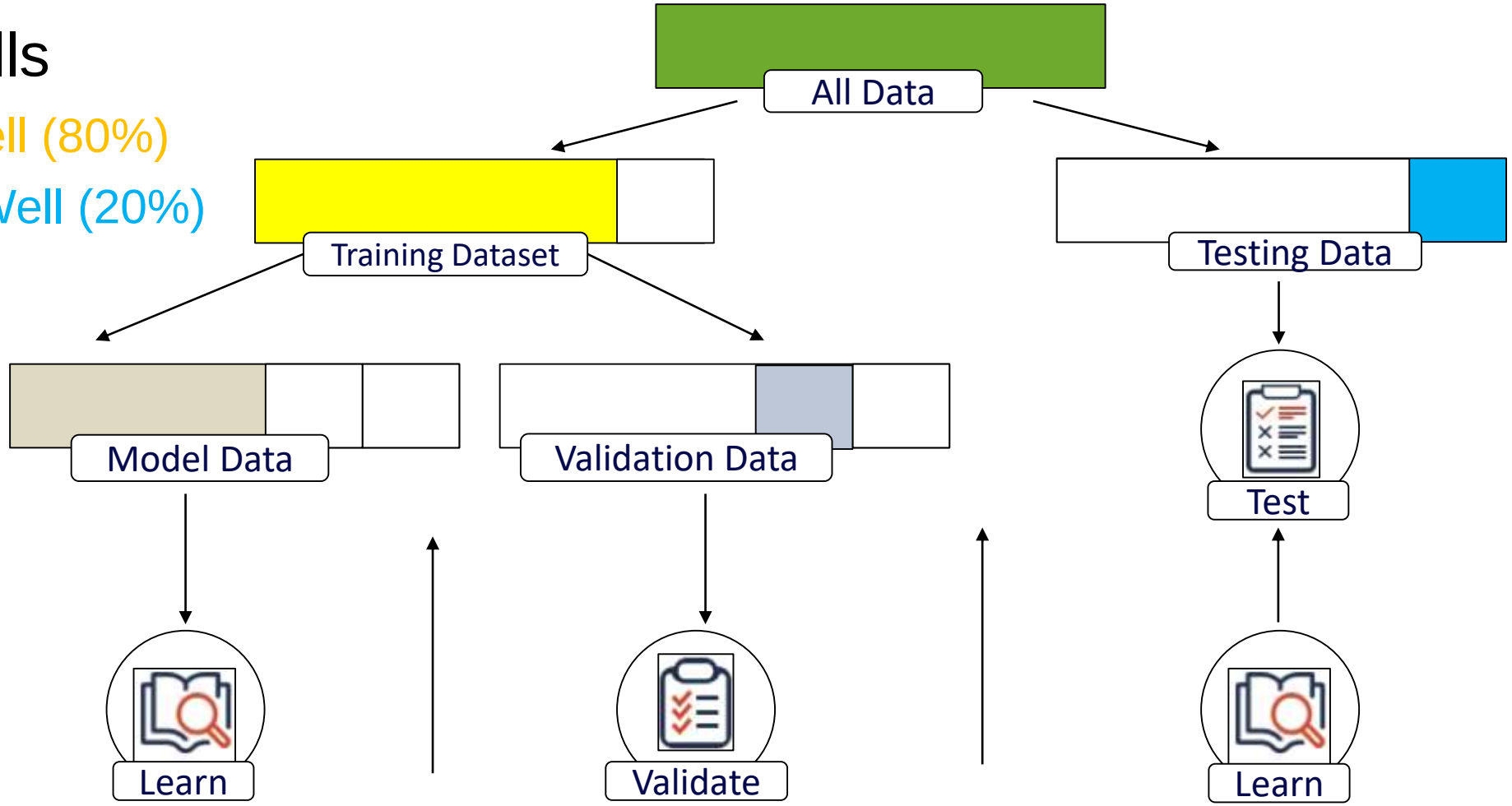

Log Measurements

- 18 Formations
  1. Dammam
  2. Rus
  3. Tayarat
  4. Ahmadi
  5. Wara
  6. Mauddud
  7. Burgan
  8. Shubaiba
  9. Zubair
  10. Ratawi
  11. Minagish
  12. Makhul
  13. Hith
  14. Gotnia
  15. Najmah
  16. Sargelu
  17. Dhruma
  18. Marrat

Well Name	MD	AT10	AT20	AT30	AT60	AT90	BS	DTCO	DTSM	GR	LCAL	RHOB	TNPH
RA-XXX	6375.0	2.5215	0.8217	1.4122	1.4514	0.9376	22.00	56.5373	105.5745	10.0984	26.1590	-9999.0	-9999.0
RA-XXX	6375.5	2.5495	0.8689	1.4357	1.5383	1.0280	22.00	56.5298	105.6357	9.4572	26.0553	-9999.0	-9999.0
RA-XXX	6376.0	2.4921	0.9219	1.4327	1.1811	0.9163	22.00	56.5510	106.0674	10.7395	25.9980	-9999.0	-9999.0
RA-XXX	6376.5	3.1600	1.0835	2.0672	1.3989	1.0125	22.00	56.6967	106.9361	13.0237	25.9223	-9999.0	-9999.0
RA-XXX	6377.0	1.5874	0.7683	1.1848	1.1985	0.8125	22.00	56.9836	108.1618	14.6266	25.8667	-9999.0	-9999.0
...	...	...	...	...	...	...	...	...	...	...	...	...	...

Well Log Features

Log Measurements

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Wireline Log Abbreviations

MD (F) : Measured Depth
BS (IN) : Bit Size
GR (GAPI) : Gamma Ray
HCAL (IN) : HRCC Caliper
NPHI (V/V) : Neutron Porosity
RT (OHMM) : True Resistivity
AT10 (OHMM) : Resistivity A10
AT20 (OHMM) : Resistivity A20
AT30 (OHMM) : Resistivity A30
AT60 (OHMM) : Resistivity A60
AT90 (OHMM) : Resistivity A90
RHOB (G/C3) : Bulk Density
DTCO (US/F) : Compressional
DTS (US/F) : Shear

Well Name	MD	AT10	AT20	AT30	AT60	AT90	BS	DTCO	DTSM	GR	LCAL	RHOB	TNPH
RA-XXX	6375.0	2.5215	0.8217	1.4122	1.4514	0.9376	22.00	56.5373	105.5745	10.0984	26.1590	-9999.0	-9999.0
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...	...	...	...	...	...	...	...	...	...	...	...	...	...

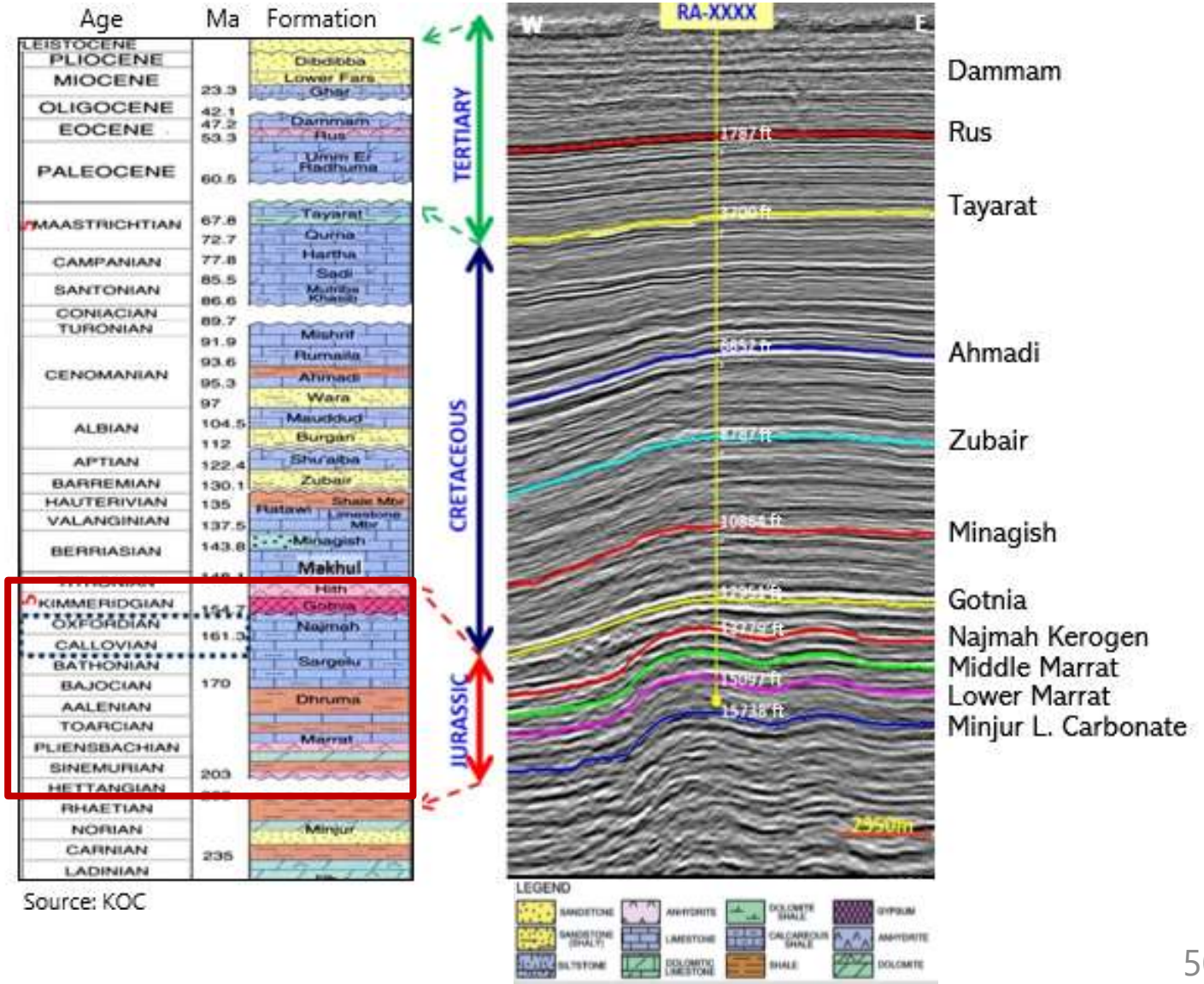
Well Log Features

Dataset Processing

- 18 Formations
  1. Dammam
  2. Rus
  3. Tayarat
  4. Ahmadi
  5. Wara
  6. Mauddud
  7. Burgan
  8. Shubaiba
  9. Zubair
  10. Ratawi
  11. Minagish
  12. Makhul
  13. Hith
  14. Gotnia
  15. Najmah
  16. Sargelu
  17. Dhruma
  18. Marrat

Evaporite
Sandstone
Shale
Carbonate

Jurassic Reservoirs



Dataset Processing

- 18 Formations
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  7. Burgan
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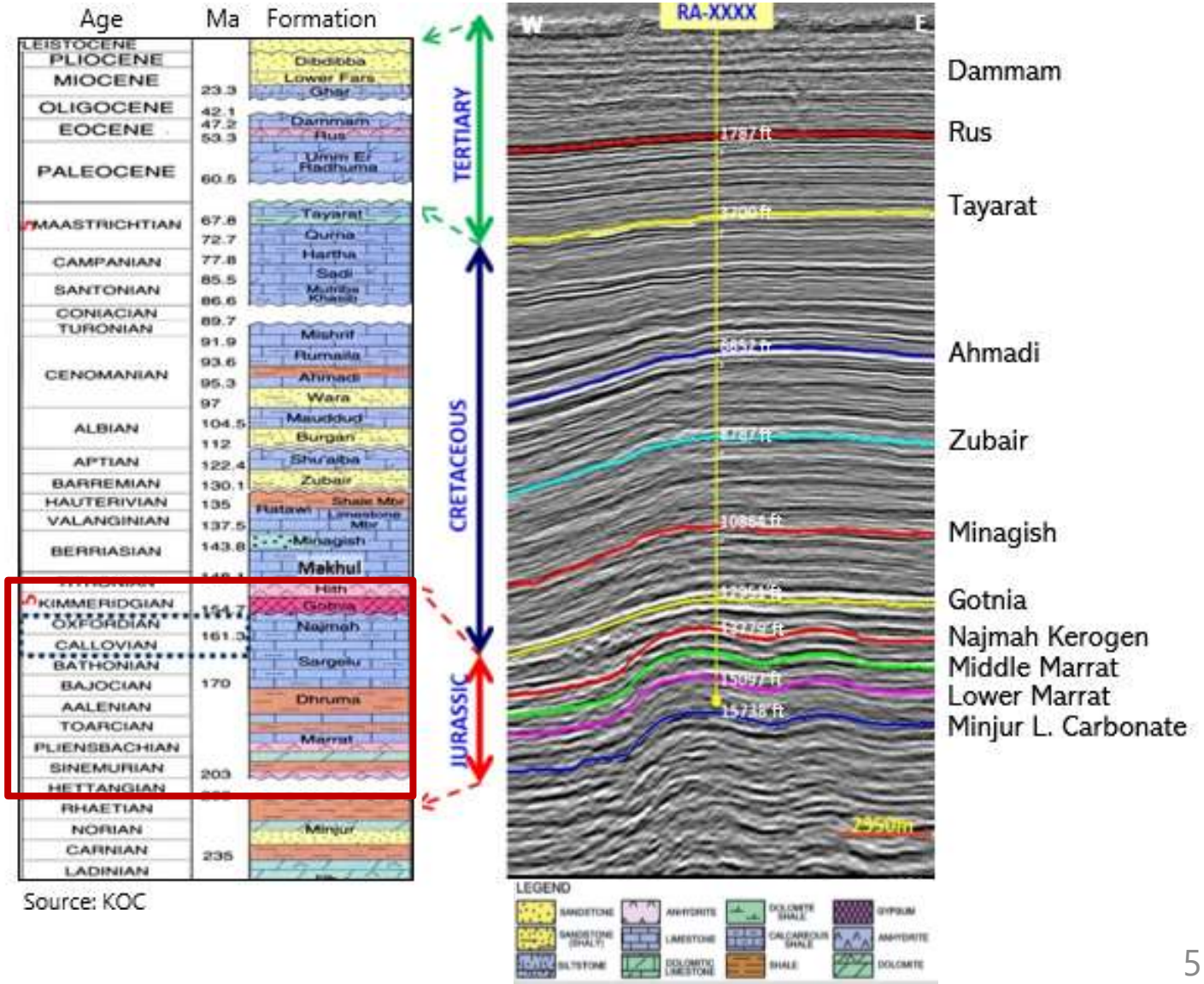
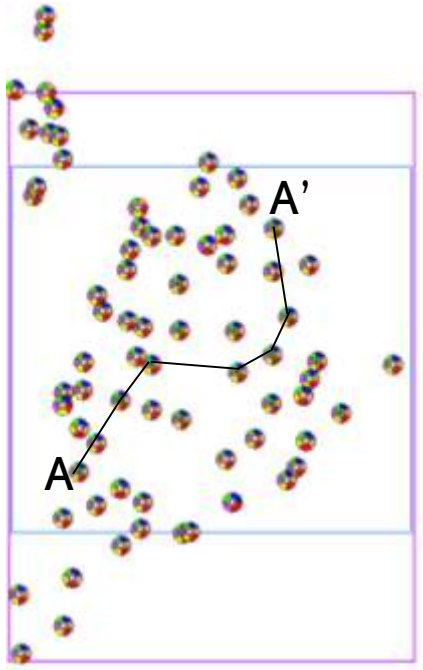
  15. Najmah
  16. Sargelu
  17. Dhruma
  18. Marrat

Evaporite
Sandstone
Shale
Carbonate

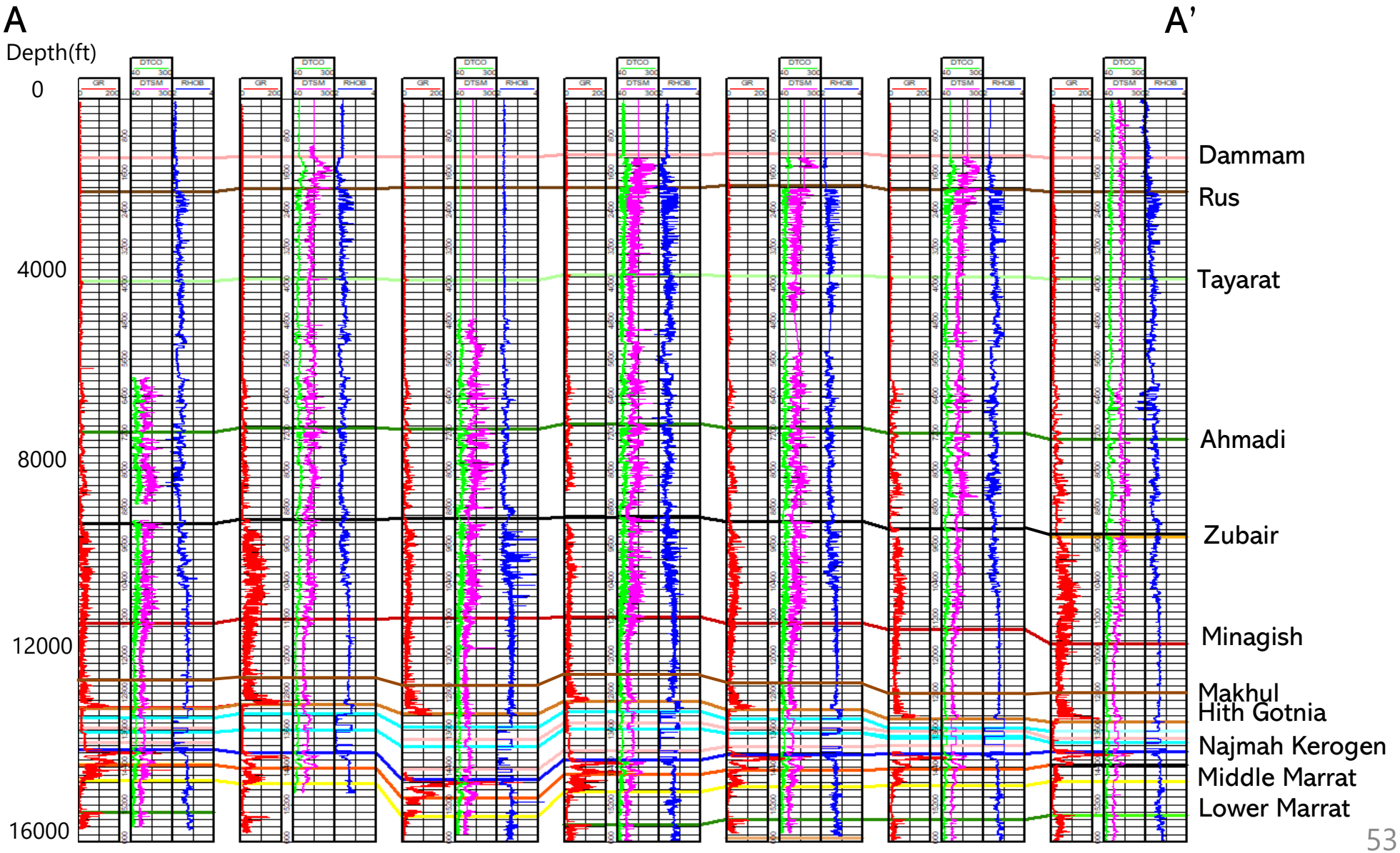
Jurassic Reservoirs



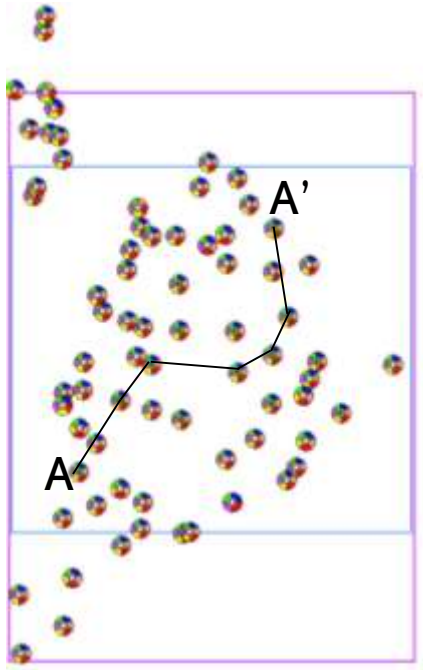
West to East Cross Section



LEGEND



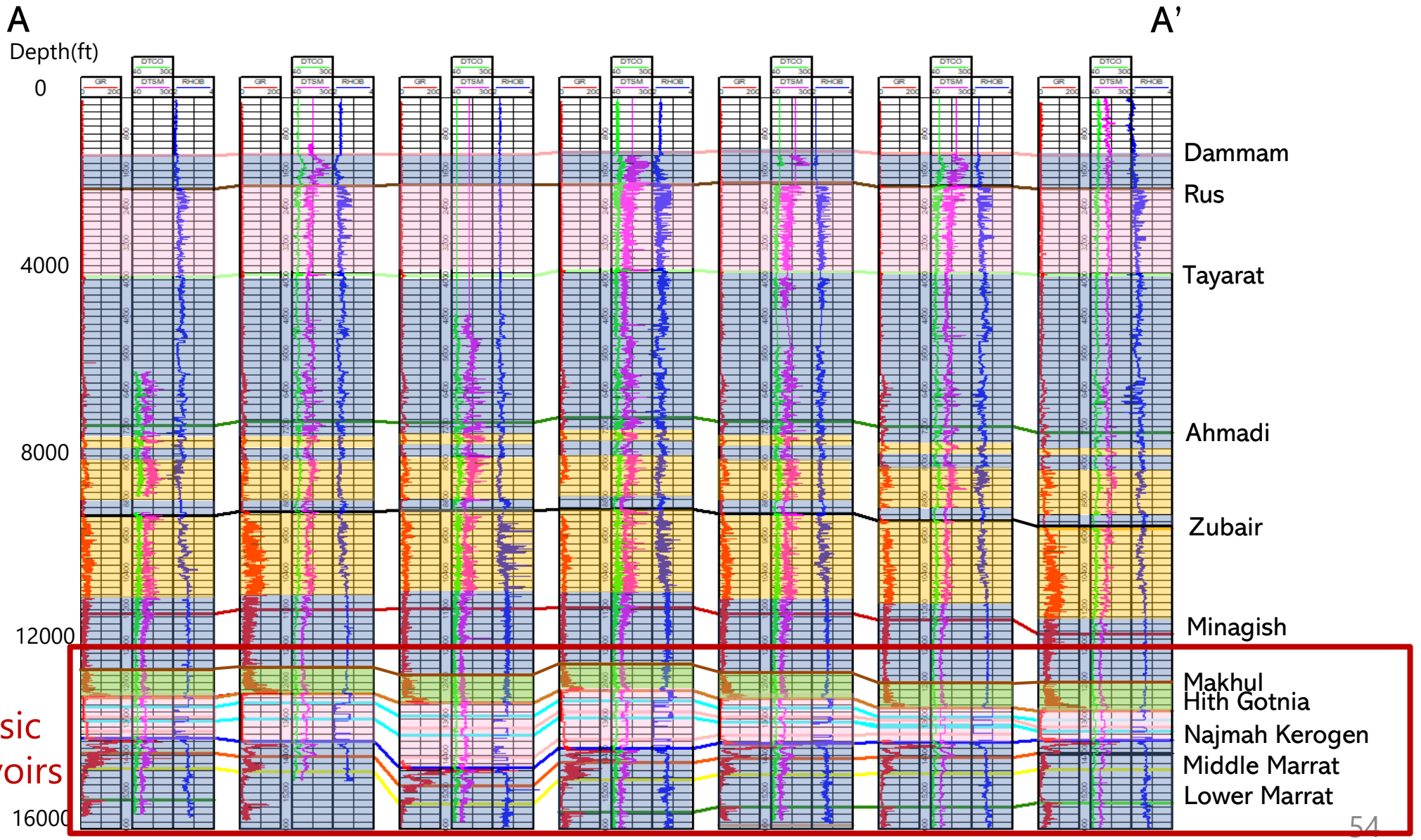
West to East Cross Section



LEGEND

- Evaporite
- Sandstone
- Shale
- Carbonate

Jurassic Reservoirs



West to East Cross Section (Jurassic Reservoirs)

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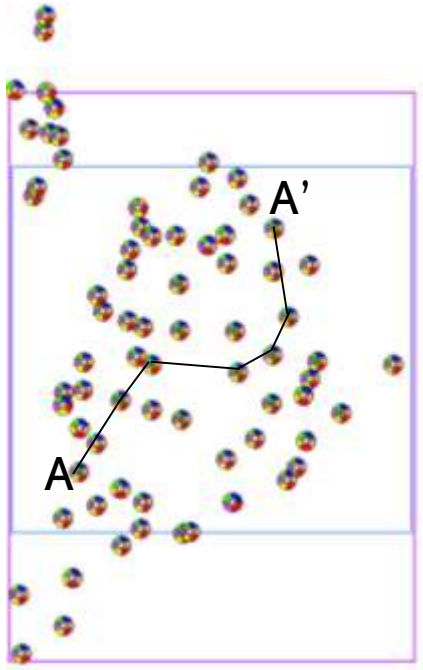
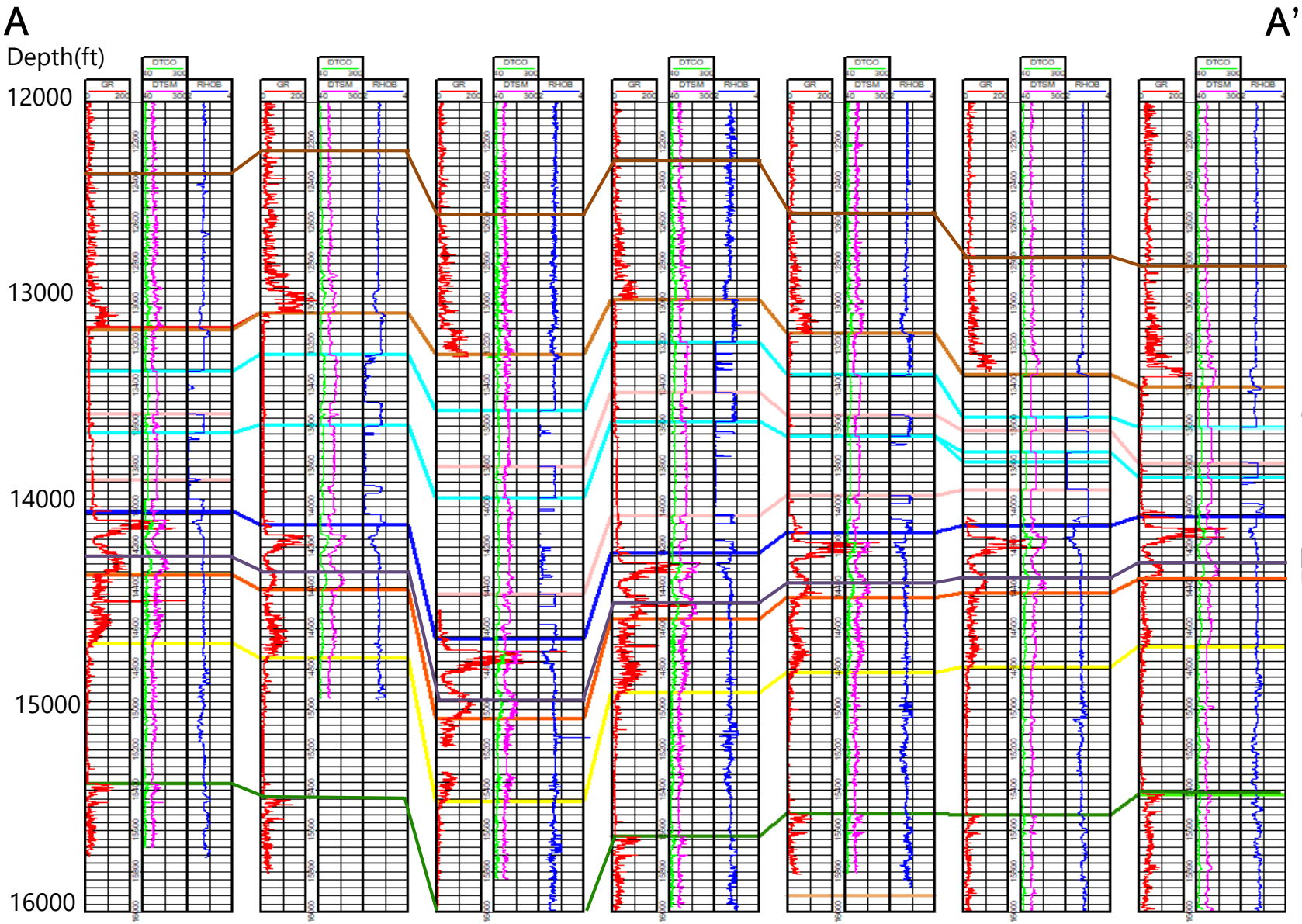


LEGEND

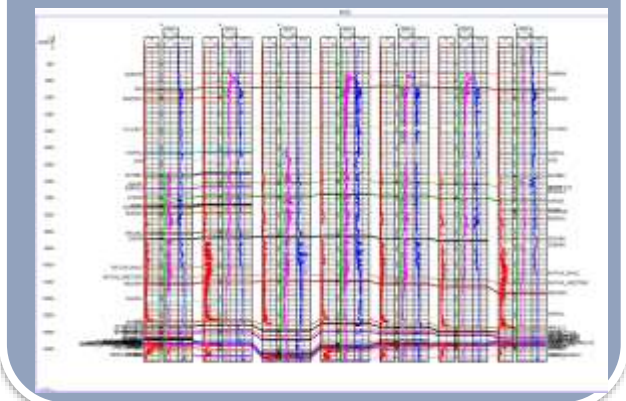


Objective

- Develop Machine Learning facies inversion workflow for mapping of unconventional reservoirs

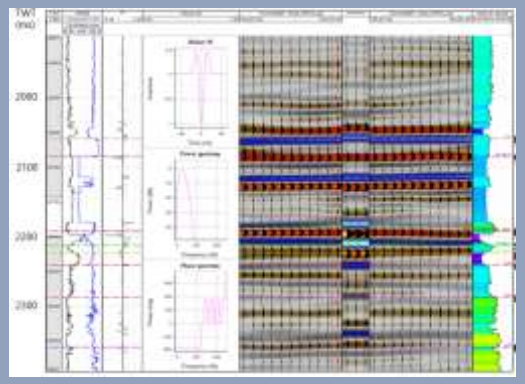
Step 1

Apply ML in well logs for facies inversion



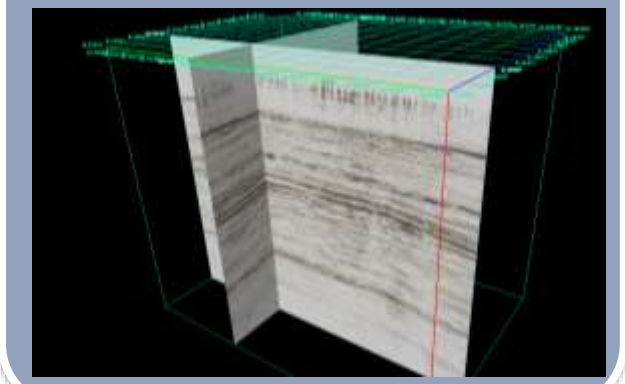
Step 2

Apply ML on seismic trace surrounding each well as a new feature



Step 3

Utilize final ML facies inversion algorithm for entire seismic volume



Objective

- Develop Machine Learning facies inversion workflow for mapping of unconventional reservoirs
- Enhance the resolution at depths by identifying and mapping the internal facies variation
- Optimize reservoir characterization and update geological model with seismic facies from Machine Learning
  - Support complex well designs/profiles
  - Facilitate casing and well placement in the Jurassic reservoir
  - Reduce HSE risk

Outline

- New KOC Dataset
- Project 1: Facies Inversion through Machine Learning
- Project 2: Multiple Attenuation

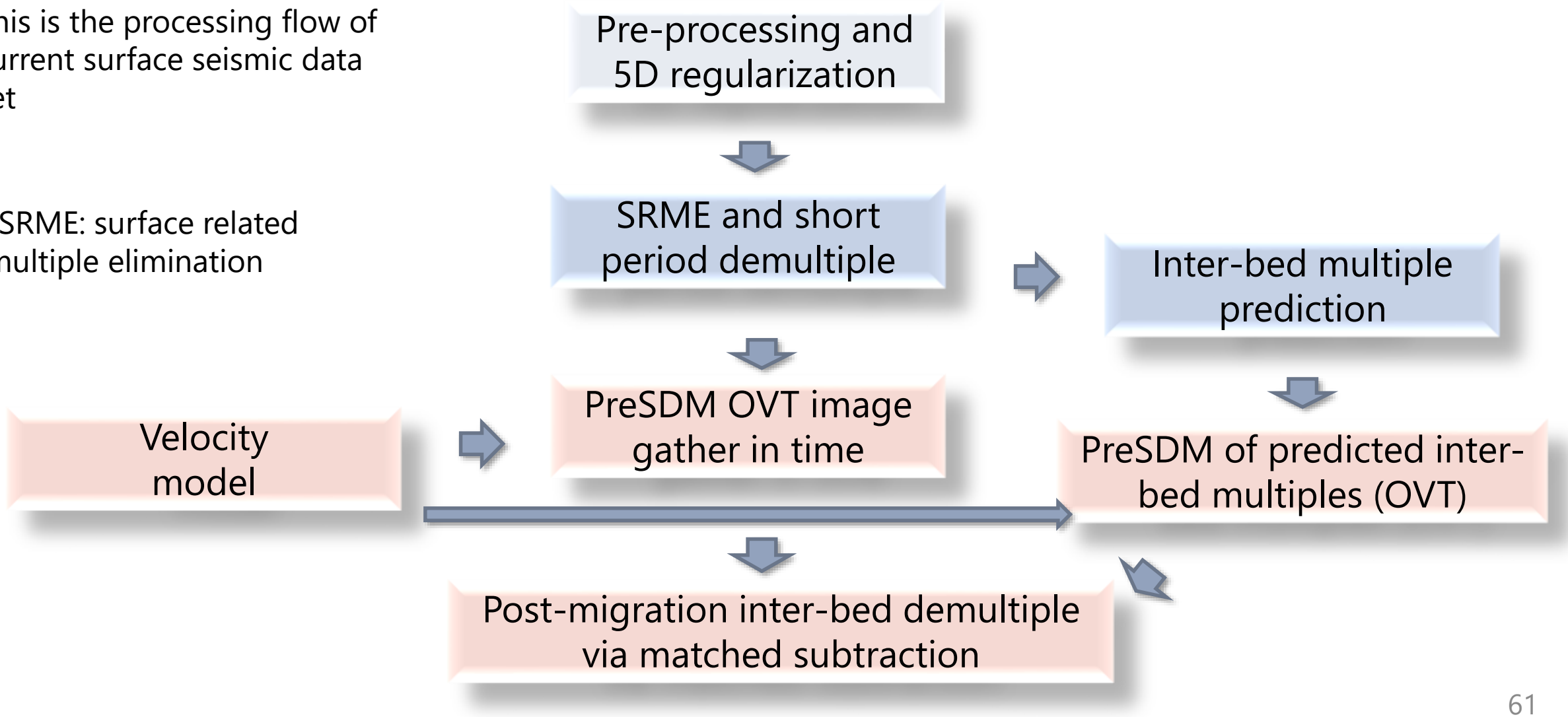
Objectives

- Understand and predict the inter-bed multiples generated from the high velocity and high impedance contrast overburden layers
- Evaluate the multiple attenuation methods used in the industry
- Attenuate inter-bed multiples and improve imaging at deep Jurassic reservoir intervals
- If possible, characterize fractures from the multiple-attenuated seismic data for the reservoir development

Demultiple-related Processing Flow

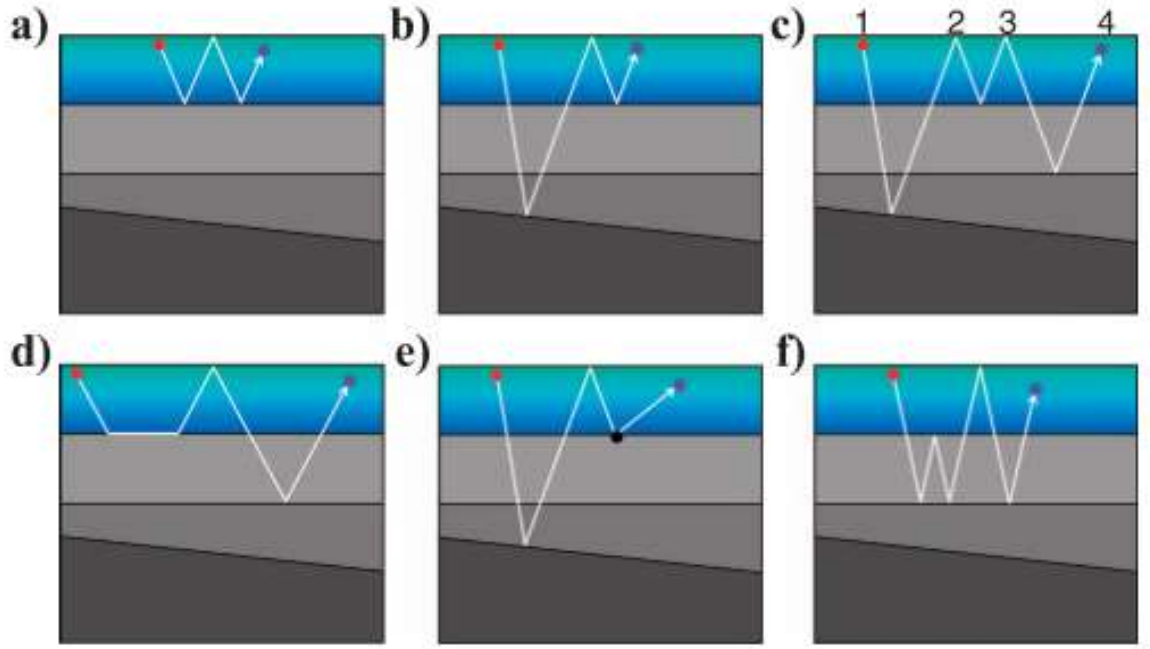
This is the processing flow of current surface seismic data set

*SRME: surface related multiple elimination



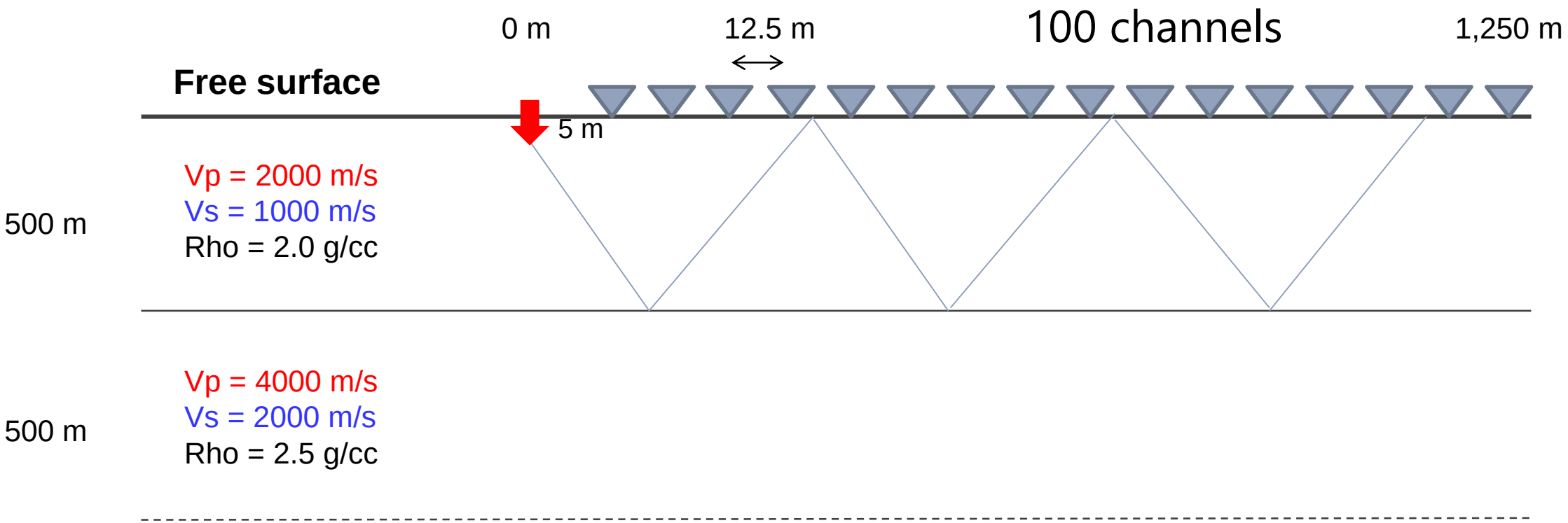
Surface Related Multiple Elimination (SRME)

- Data driven surface-related multiple prediction
- Adaptive multiple subtraction



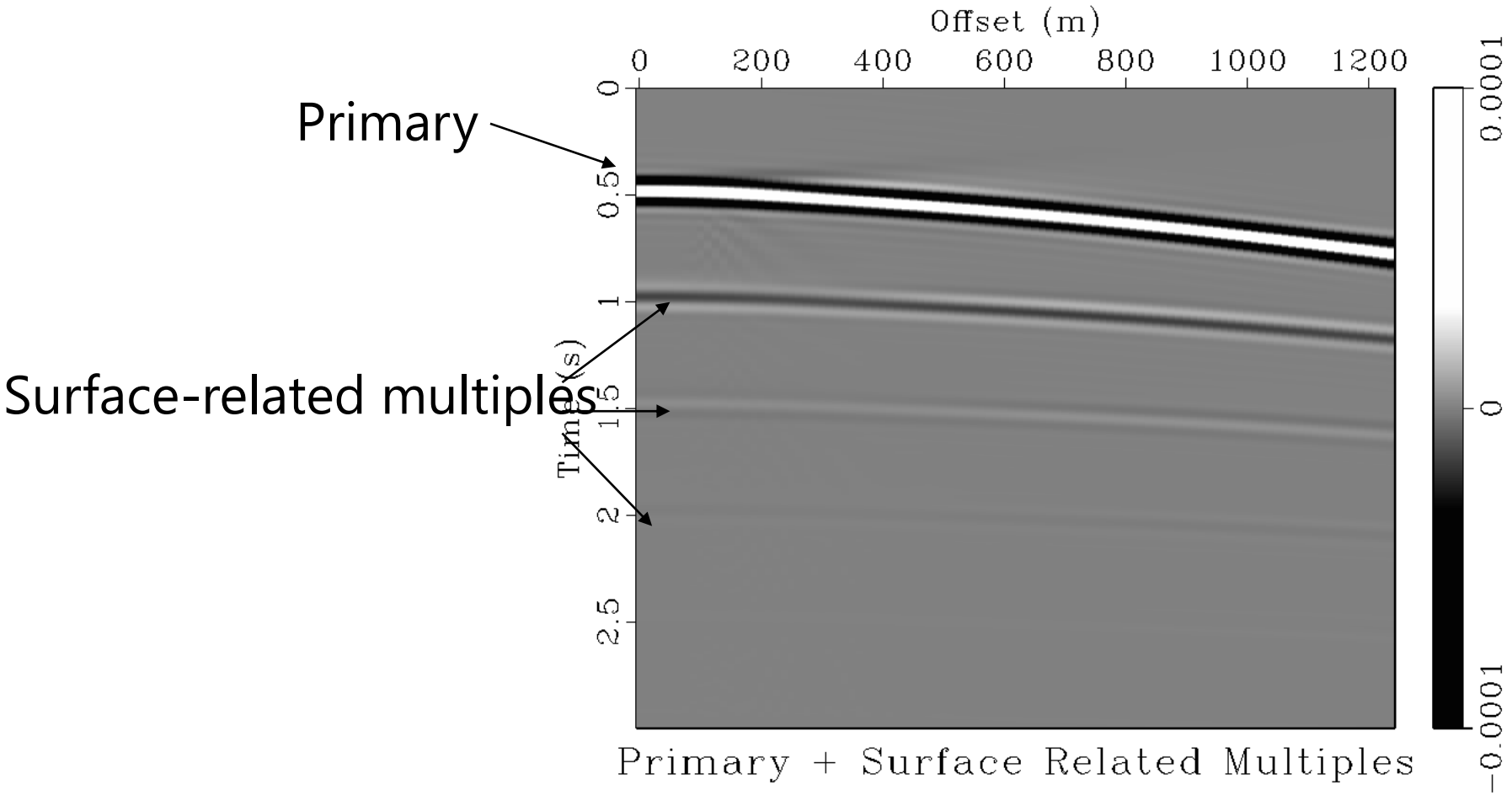
Dragoset et al., 2010

2-layer Isotropic Acoustic Model

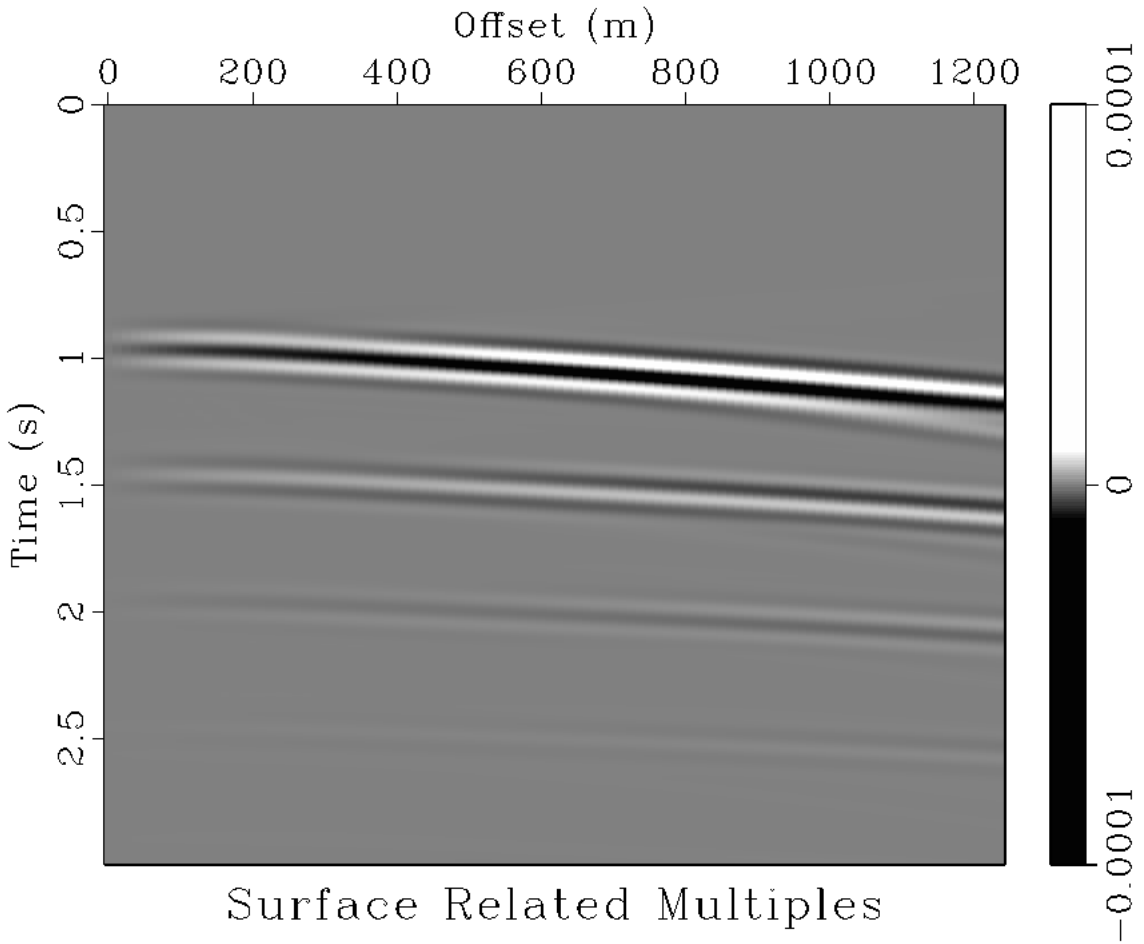


Parameters:
Vertical source
Free surface on
Frequency: 20 Hz

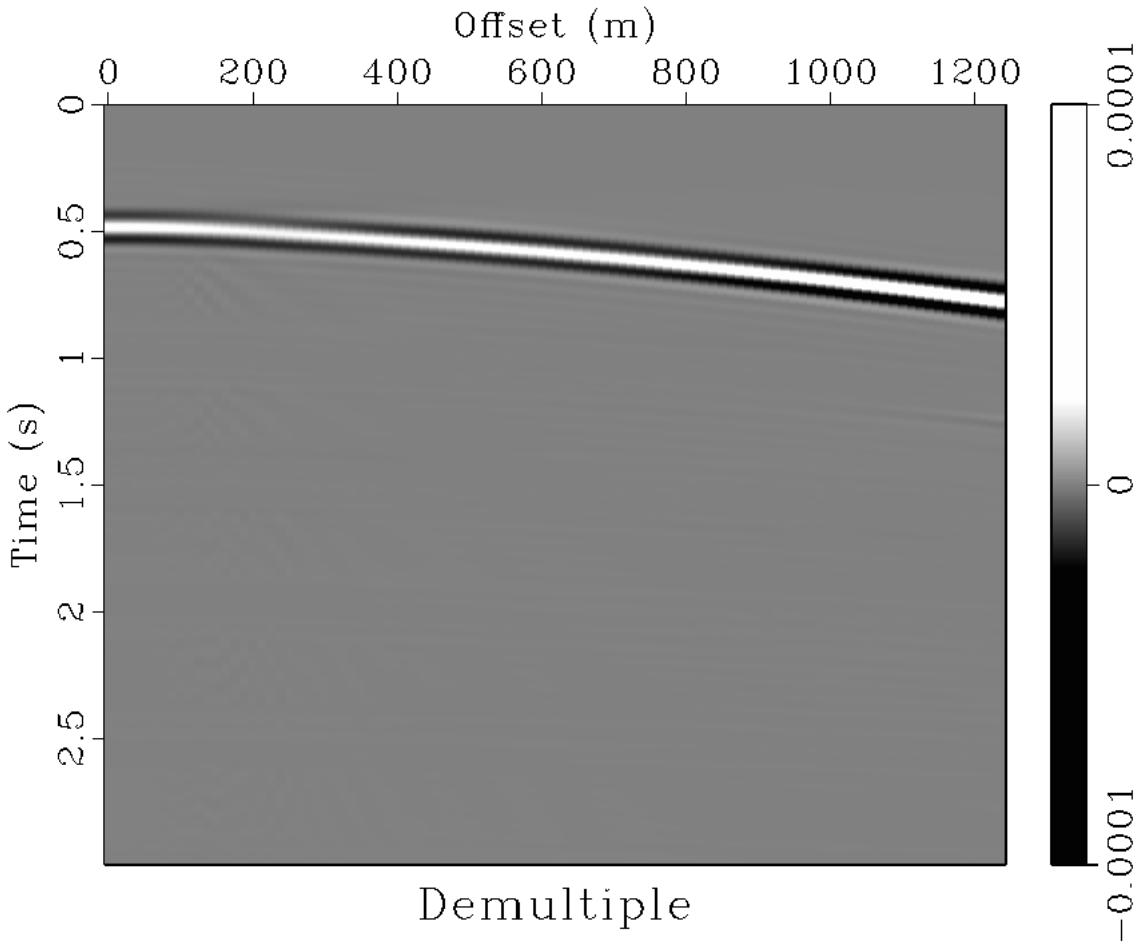
Primary with Surface Related Multiples



Surface Related Multiple Prediction



After Adaptive Subtraction



Future work

- Zero-offset/walkaway/3D VSP data
  - Better understand the inter-bed multiple and converted waves
  - Understand near surface complexity

- Continue on evaluating demultiple methods used in the industry
  - SRME
  - Inverse scattered series
  - Marchenko equation

Acknowledgement

Special thank you to Kuwait Oil Company (KOC)

Acknowledgement

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Thank you RCP industry sponsors

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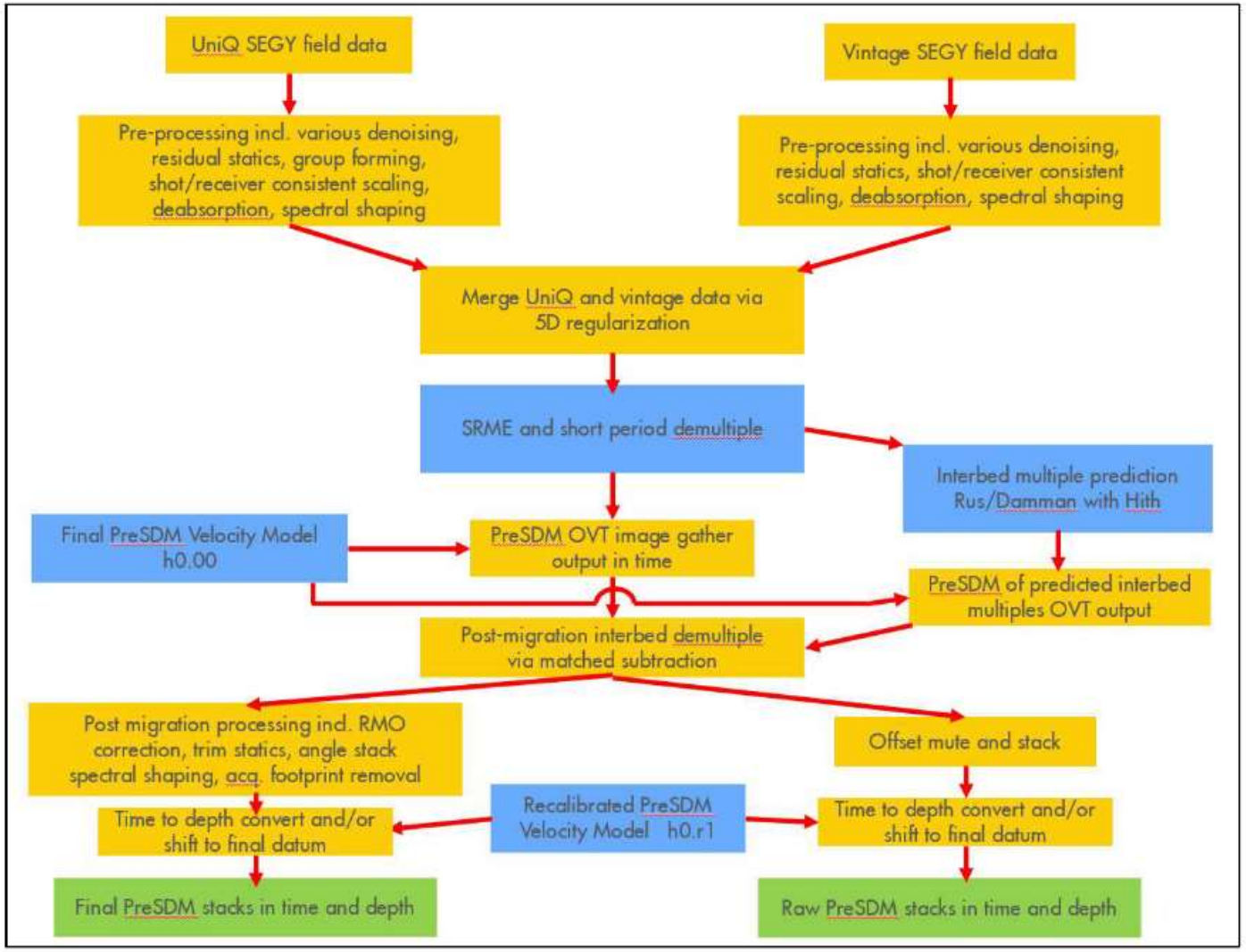
Questions ?

Seismic data processing flow



Synthetic traces in an arbitrary line