TraceSeis Inc.
Geophysical Services

SeisMod

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SeisTool: Seismic – Rock Physics Tool

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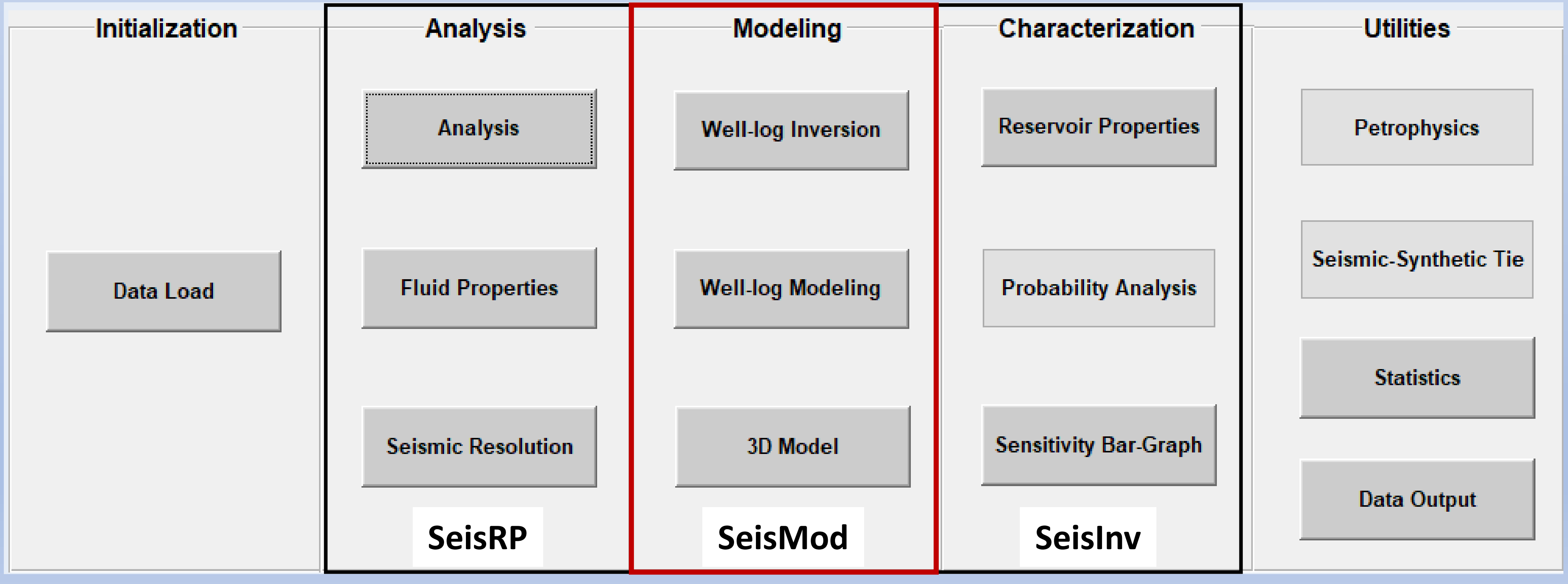
Consists of three modules, each with three programs. The analysis and modeling modules (**SeisRp** and **SeisMod**) are based on state-of-the-art rock physics relationships. These support the reservoir characterization module (**SeisChar**) in which parameters to compute reservoir properties (ϕ, lithology and fluids) are estimated through linear inversion of attributes computed from well-log or synthetic data



State of development to April 2022. Dark gray buttons correspond to operational programs

SeisTool: Seismic – Rock Physics Tool

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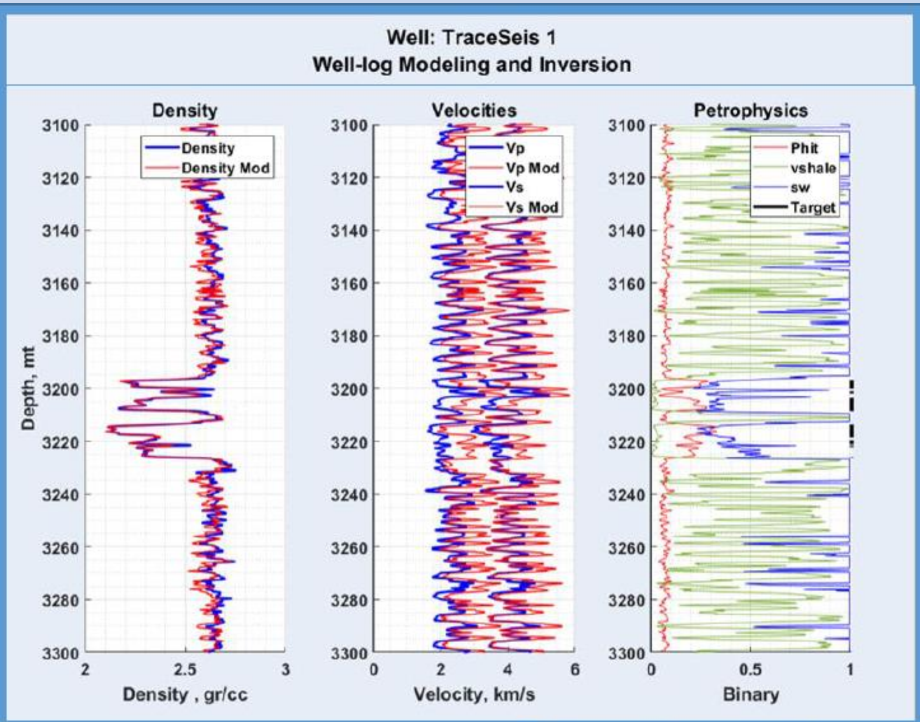
- SeisRP
- **SeisMod**
  - **A rock physics model is created. Moduli and densities of rock constituents are estimated through non-linear inversion of V_P, V_S and density logs**
  - **Forward models well-logs (Vp, Vs and density) using the rock physics model. The model incorporates volume fractions, moduli, and densities of constituents**
  - Rock properties are modeled for perturbations of the in-situ reservoir properties
  - Based on effective media theory. Minimum heuristic or empirical relationships are used
- SeisChar

Binary well, before well-log inversion



	Mineral	k	rho	mu
1	Sand	38	2.6500	45
2	Shale	19	2.8200	12

	Fluid	k	rho
1	Gas	0.0702	0.1760
2	Brine	2.6560	0.9941

Well-log Modeling

The red curves in tracks 1 and 2 are the modeled ρ, Vs and Vp using the moduli and densities in the tables above. The blue lines are measured logs

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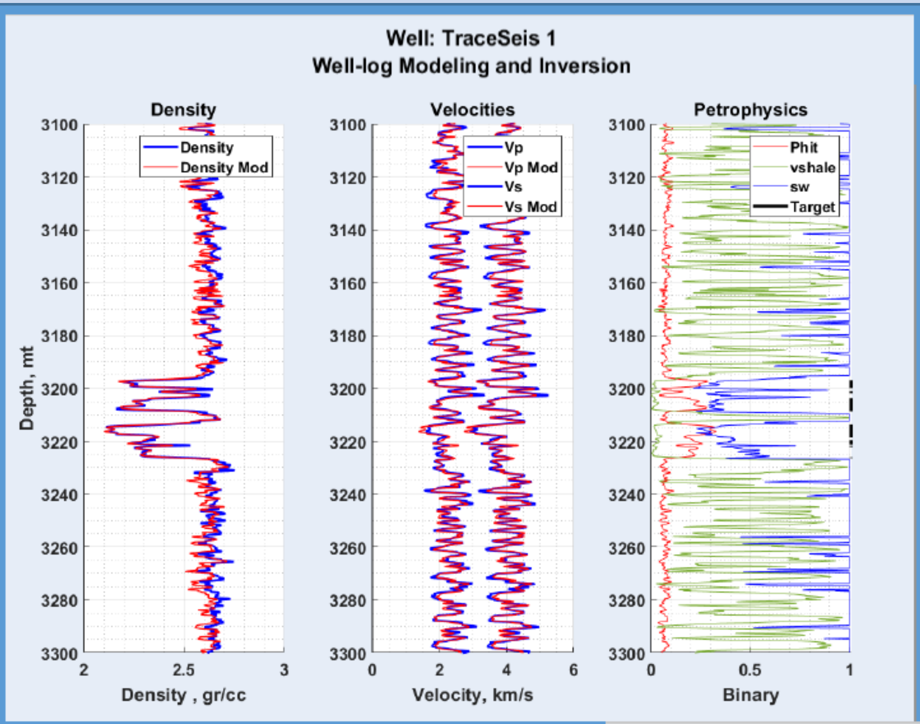
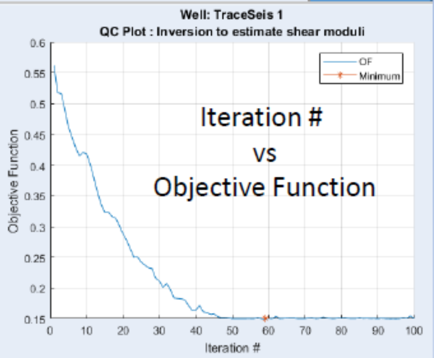


Well-log Inversion

The modeled curves are a close match to the measured ones after moduli and densities are computed through non-linear inversion of rock properties.



SeisMod: Well-log inversion

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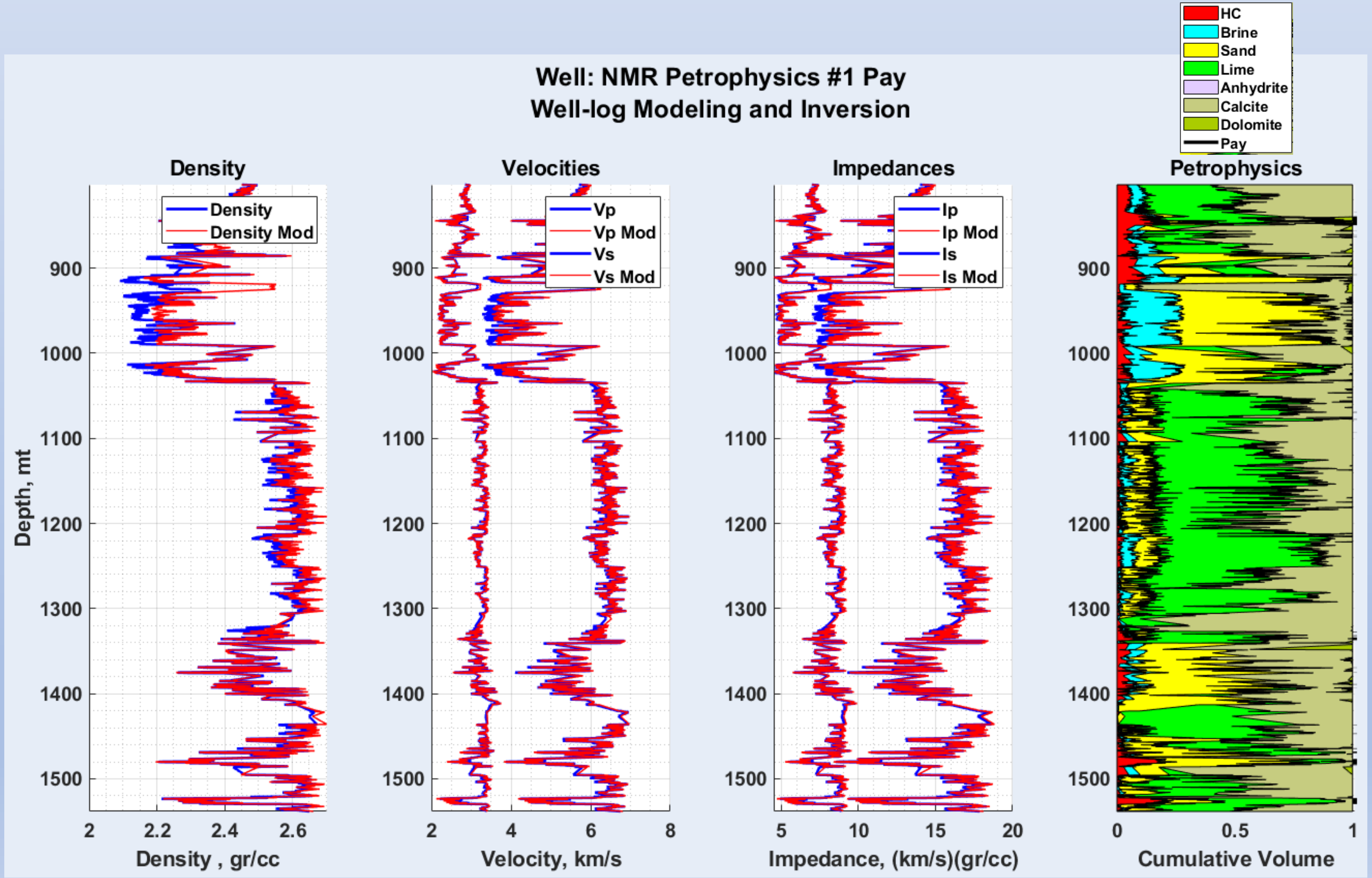

	Mineral	k, GPa	rho, gr/cc	mu, GPa	Organic
1	Sand	36.2440	2.6639	46.2414	No
2	Lime	97.9846	2.7515	35.0867	No
3	Anhydrite	59	2.9700	30	No
4	Calcite	71.7529	2.5849	30.1709	No
5	Dolomite	84.1264	2.9100	48.4298	No

The image at left shows the **modeled** and **measured** logs of a multi-mineral well. Moduli and densities (table above) are computed through well-log inversion.

The image below shows the effective media relations used.

Rock Physics Model

Solids' Model	HS Average
Porosity Model	Krief
mk 2.99	mMu 3.04
Finalized	DISABLED
Fluids into Matrix	Gassmann
Fluids' Model	Wood

SeisTool: Seismic – Rock Physics Tool

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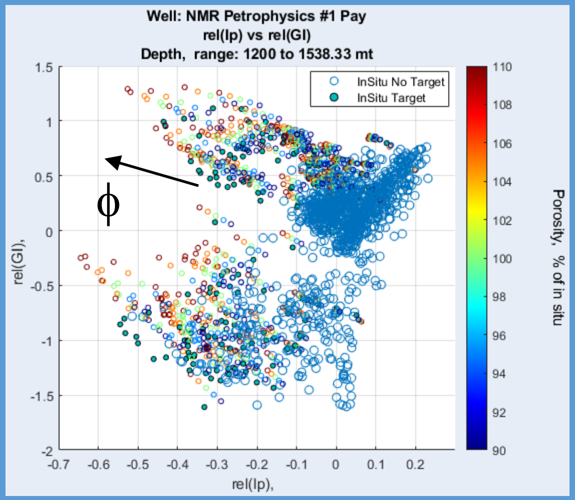

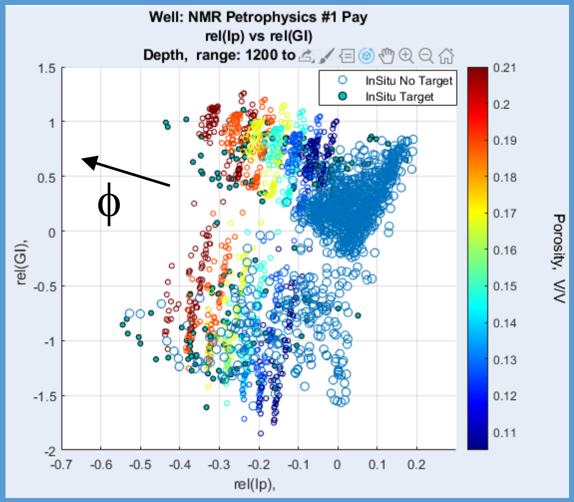

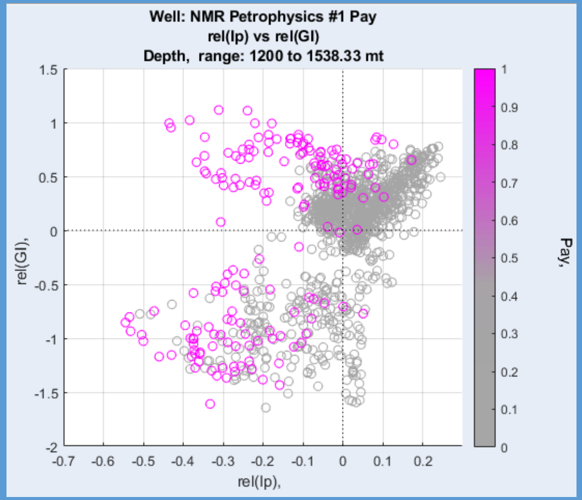

Cross-plots show relative acoustic impedance (rel(AI)) versus relative gradient impedance (rel(GI)).

Porosity is modified:

- **Percent of in-situ (upper left) From 90% to 110%**
- **Constant porosities (upper right) from mean porosity minus one standard deviation to mean porosity plus one standard deviation.**

Perturbations are made in pay points (magenta points at left)

SeisMod: Well-log and Seismic Modeling

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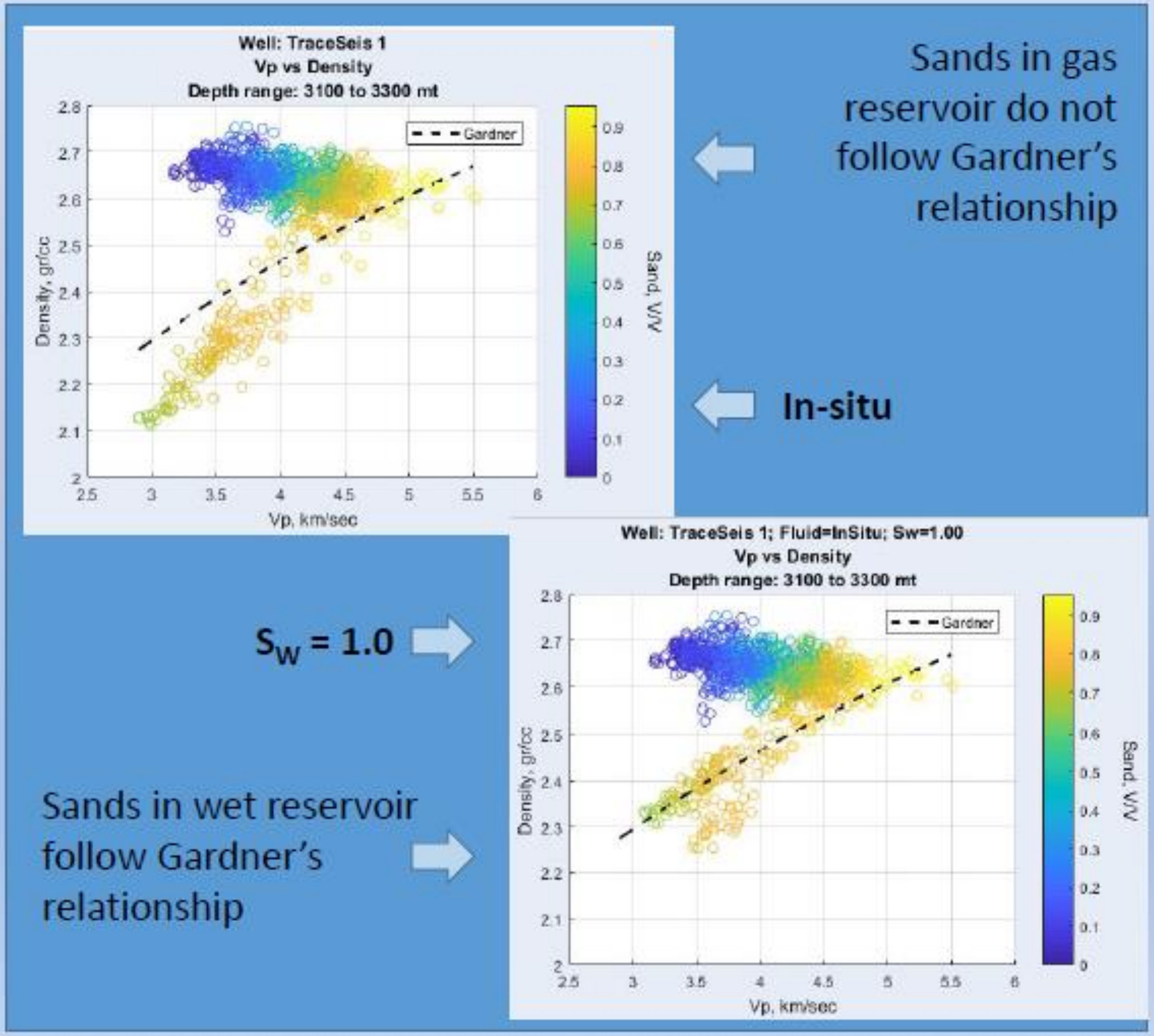
The Rock Physics Model (RPM) is the basis of the well-log and seismic modeling.

The RPM is constituted of the effective media relations and the moduli and densities of constituents that optimally reconstruct (model) the measured logs.

The images at right show the case of fluid substitution.

Images in the following slides are examples of well-log and seismic models for different reservoir conditions.



SeisMod: Well-log Modeling

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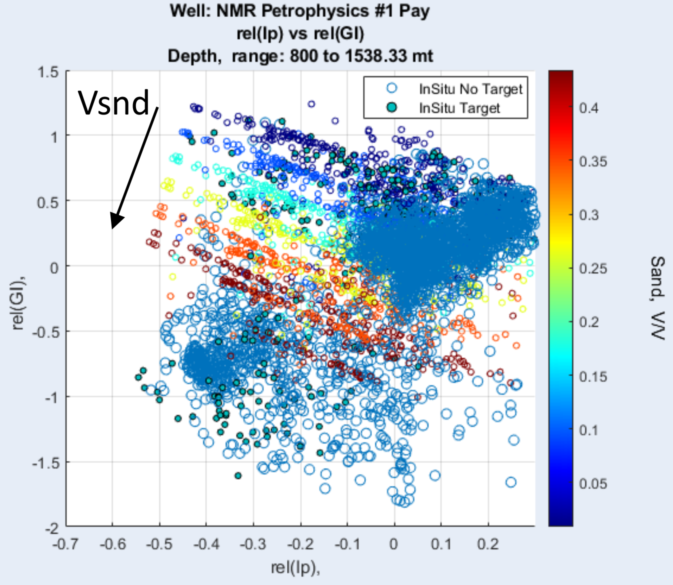
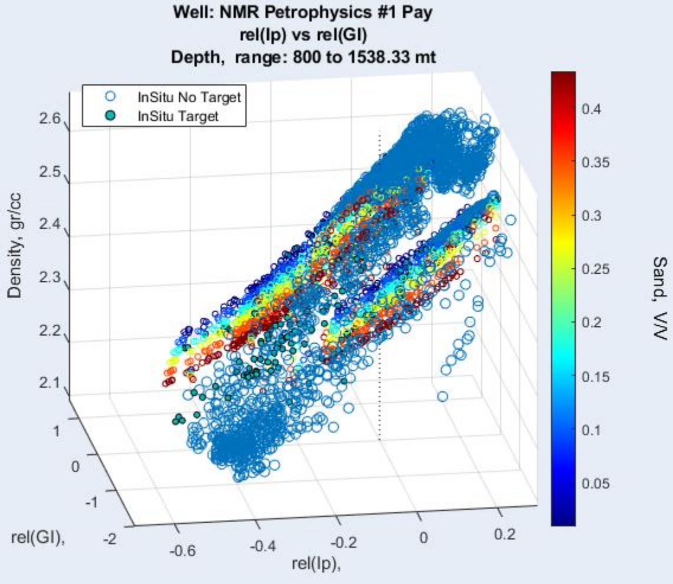
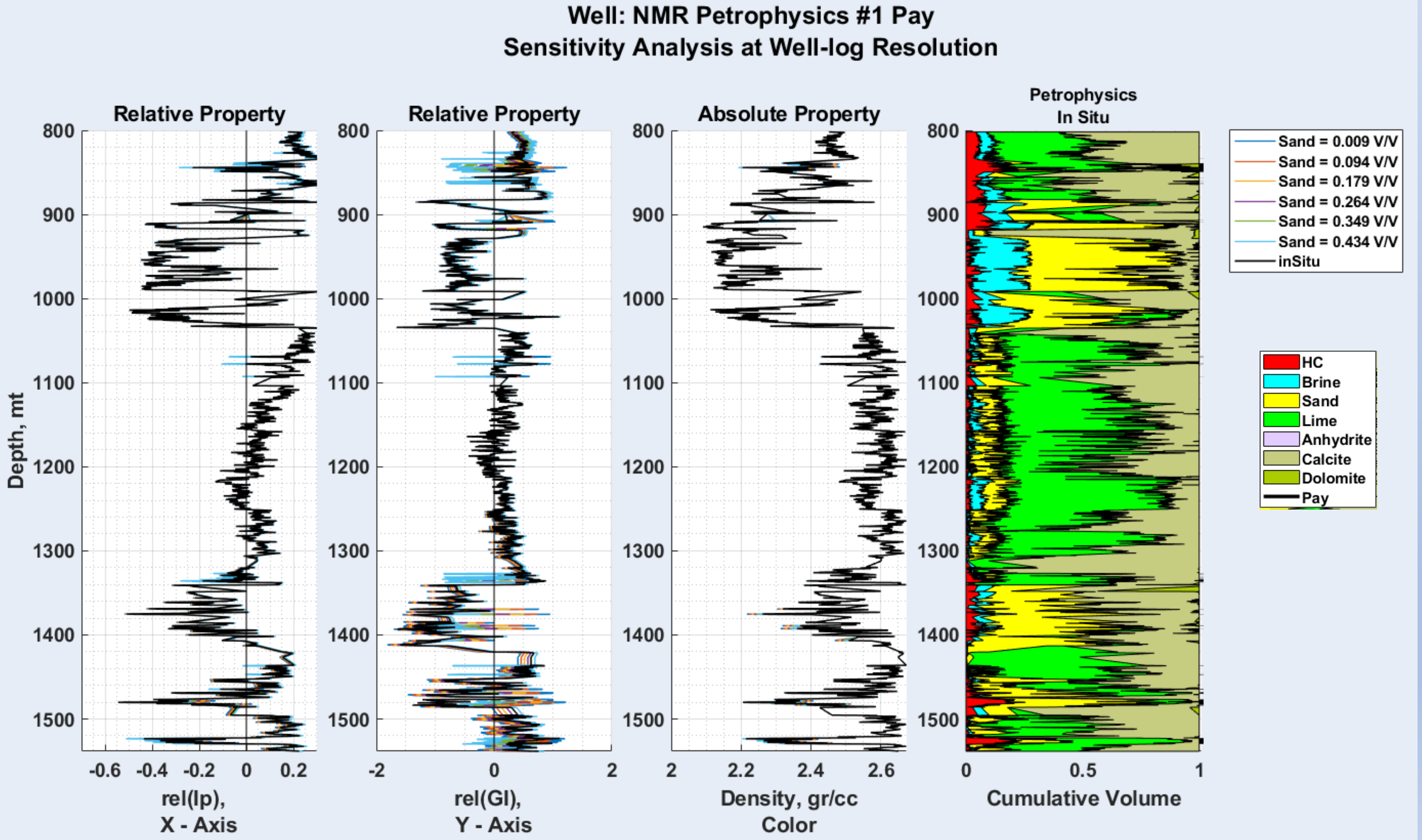
Sand percent is modified in pay-flag points. From mean minus one standard deviation to mean plus one standard deviation. The 3D cross-plot (lower left) shows different rock properties for shallow and deep reservoirs







SeisMod: Well-log Modeling
Seismic Resolution 3-12-100-150 Hz

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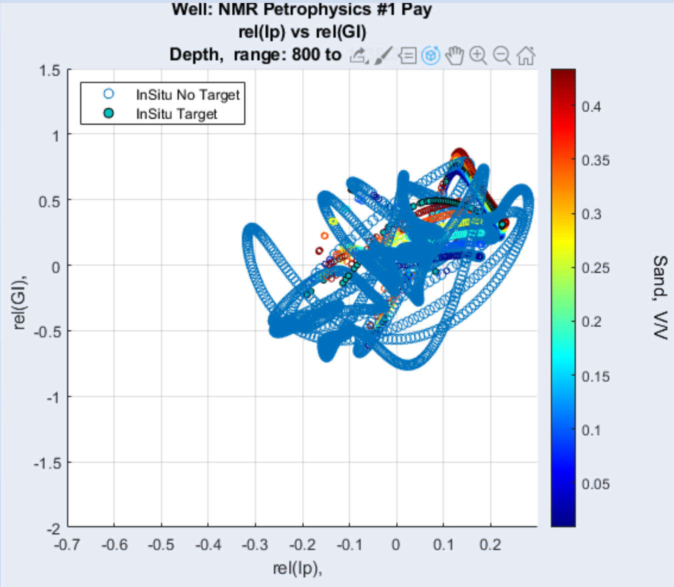
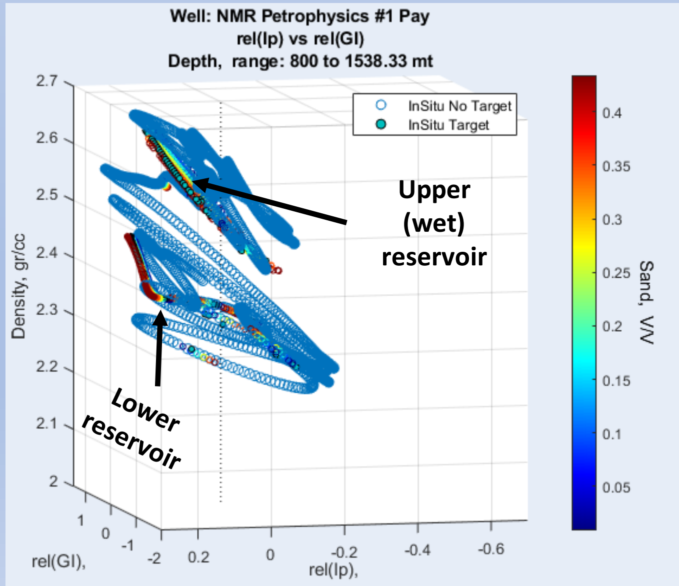
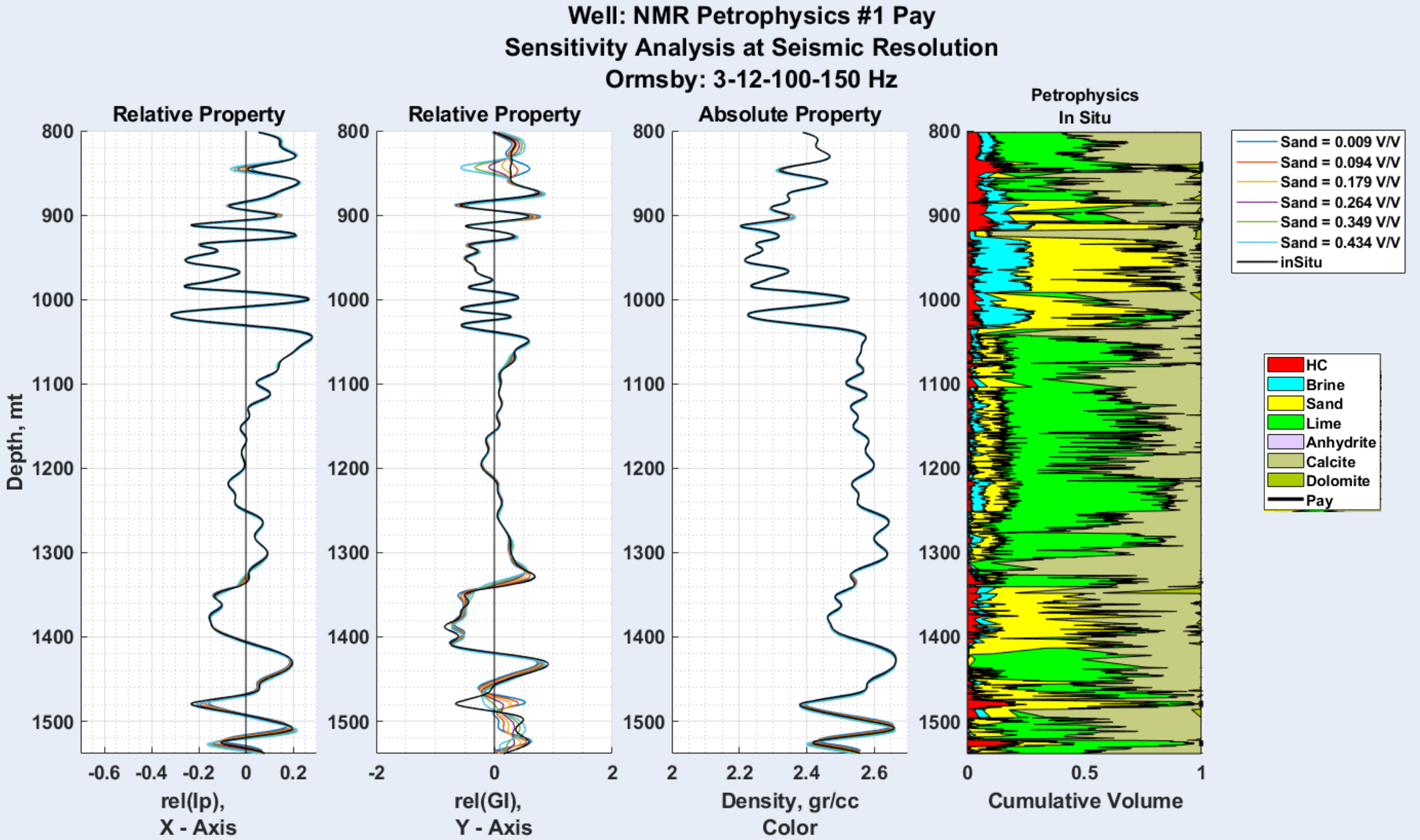
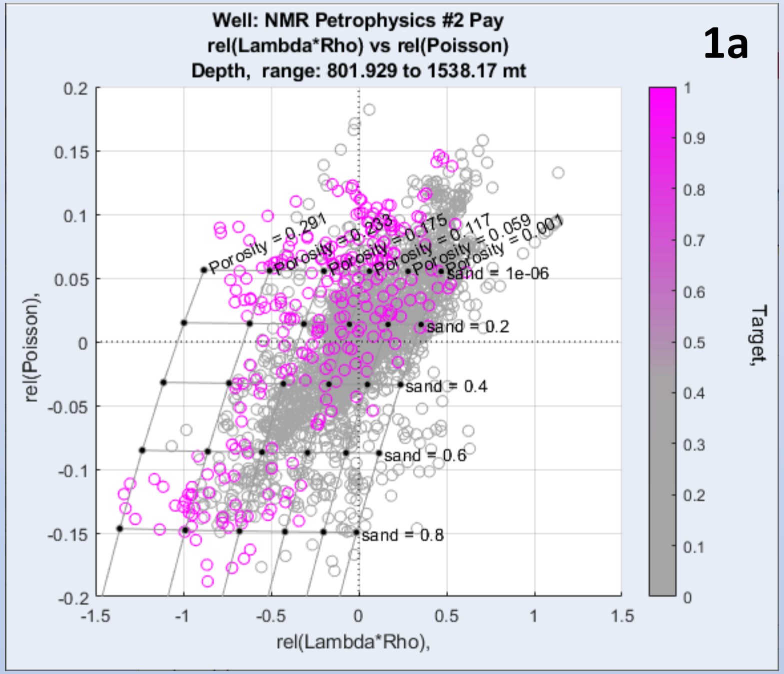
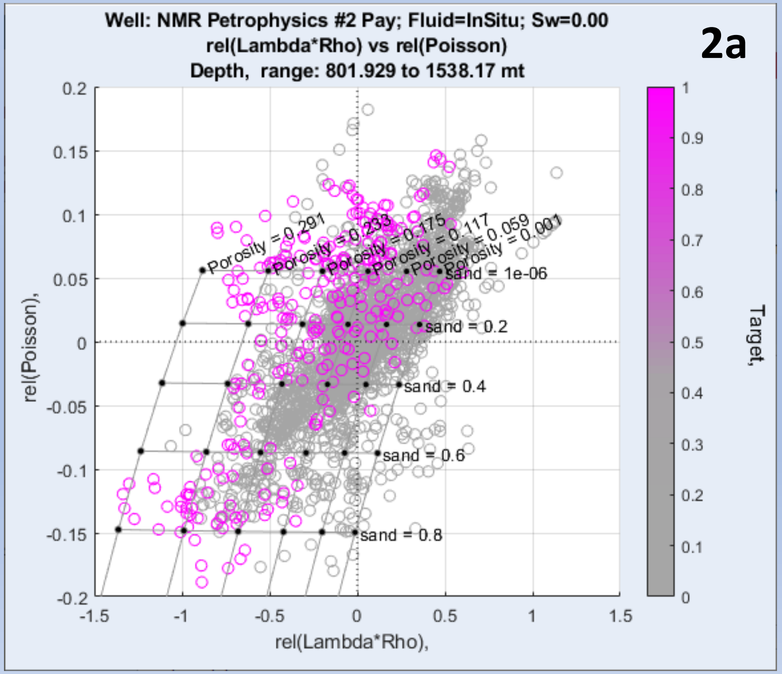


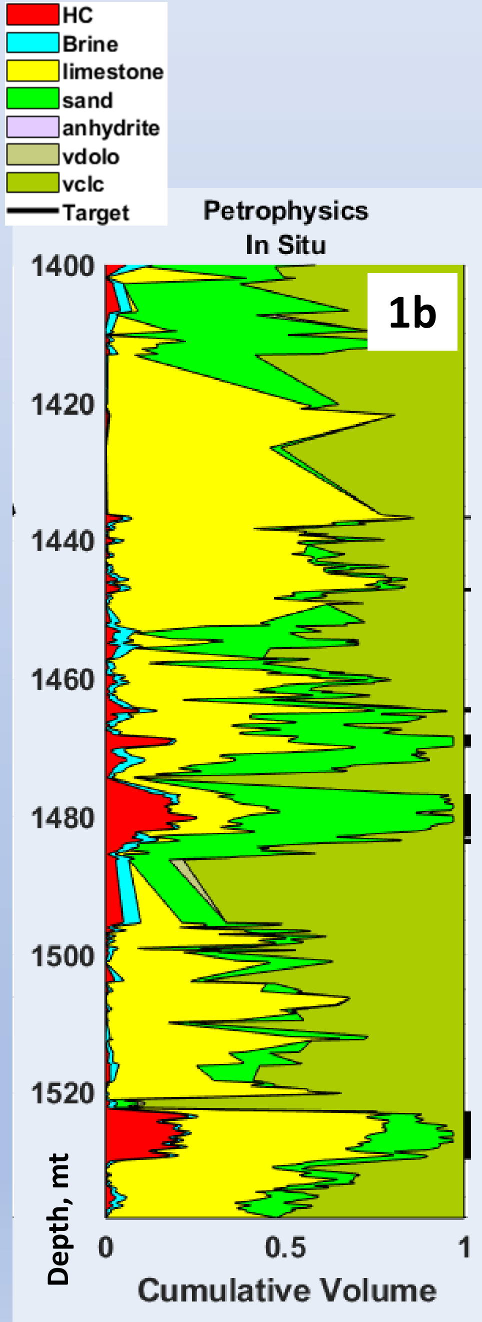


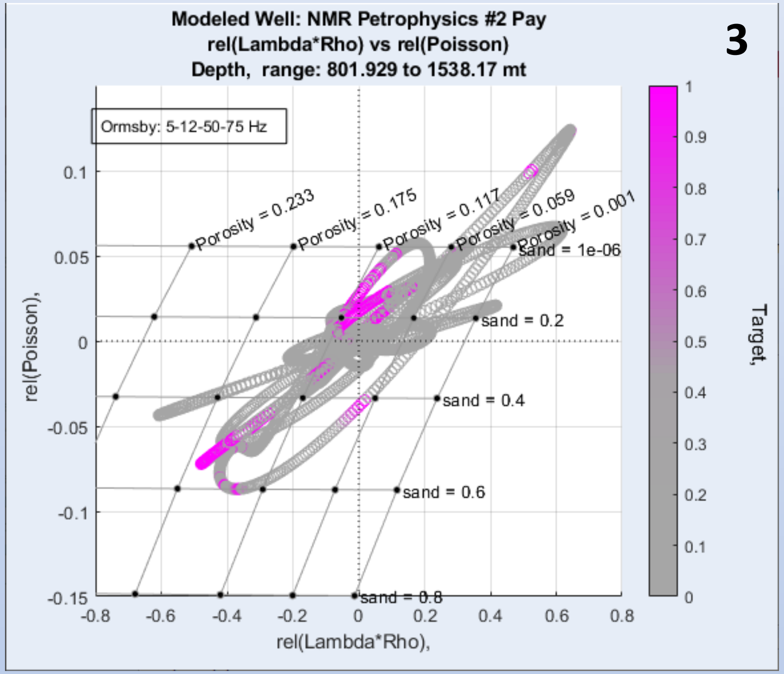
Sand percent is modified in pay-flag points and rel(Ip), rel(GI) modeled at seismic resolution for different sand volumes. The pay points are few and sparse, which results in poor lithology discrimination in cross-plots (compare with previous slide). Upper and lower reservoirs appear separated in the 3D cross-plot.









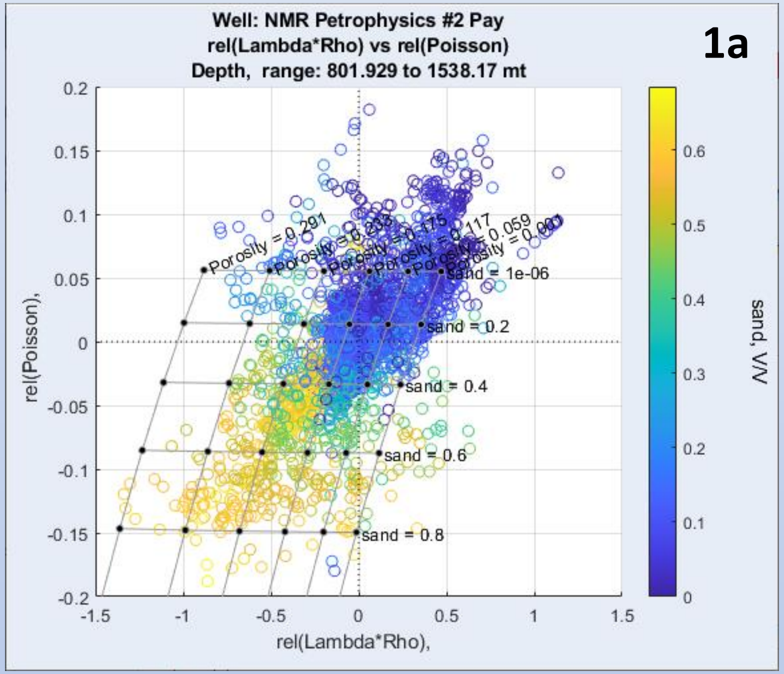


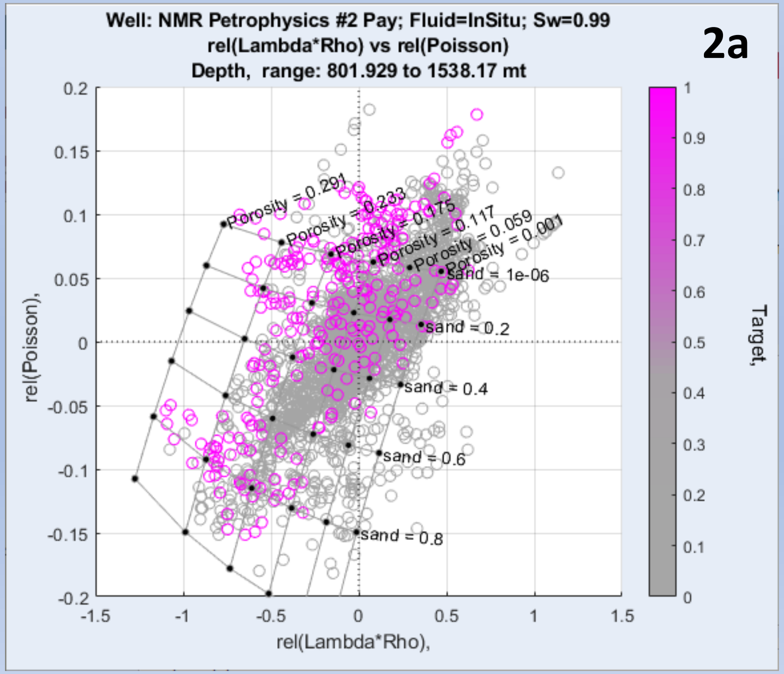
Templates are created based on the rock physics model (RPM). The reservoir properties for the template (porosity and sand in the cross-plots shown) are assigned 36 constant values and the rock properties (rel(Lambda*Rho and rel(Poisson)) are computed for these through the RPM.

Template values are only computed for the target formations (where target flag = 1)

For the case of multimin evaluations, the remaining lithologies are adjusted proportionally, which may result in values at the target that may fall outside the template

Figure 1a. Measured rock properties.
Figure 1b. In-situ petrophysical evaluation. Note that in-situ S_W at target ≈ 0
Figure 2a. Rock properties. Fluid substitution $S_W = 0$.
Figure 3. Measured rock properties at seismic resolution.





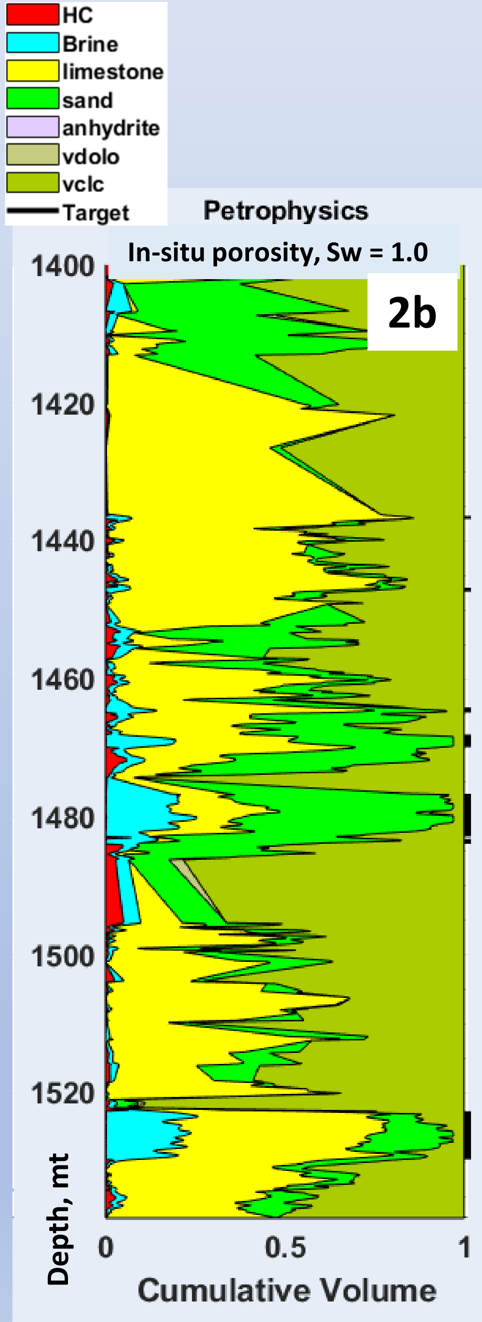


Figure 1a. In-situ rock properties color coded by sand volume.

Figure 2a. Properties (rel(Lambda*Rho) and rel(Poisson)) for the S_W = 0.99 case, as illustrated in Petrophysics plot – **Figure 2b**.

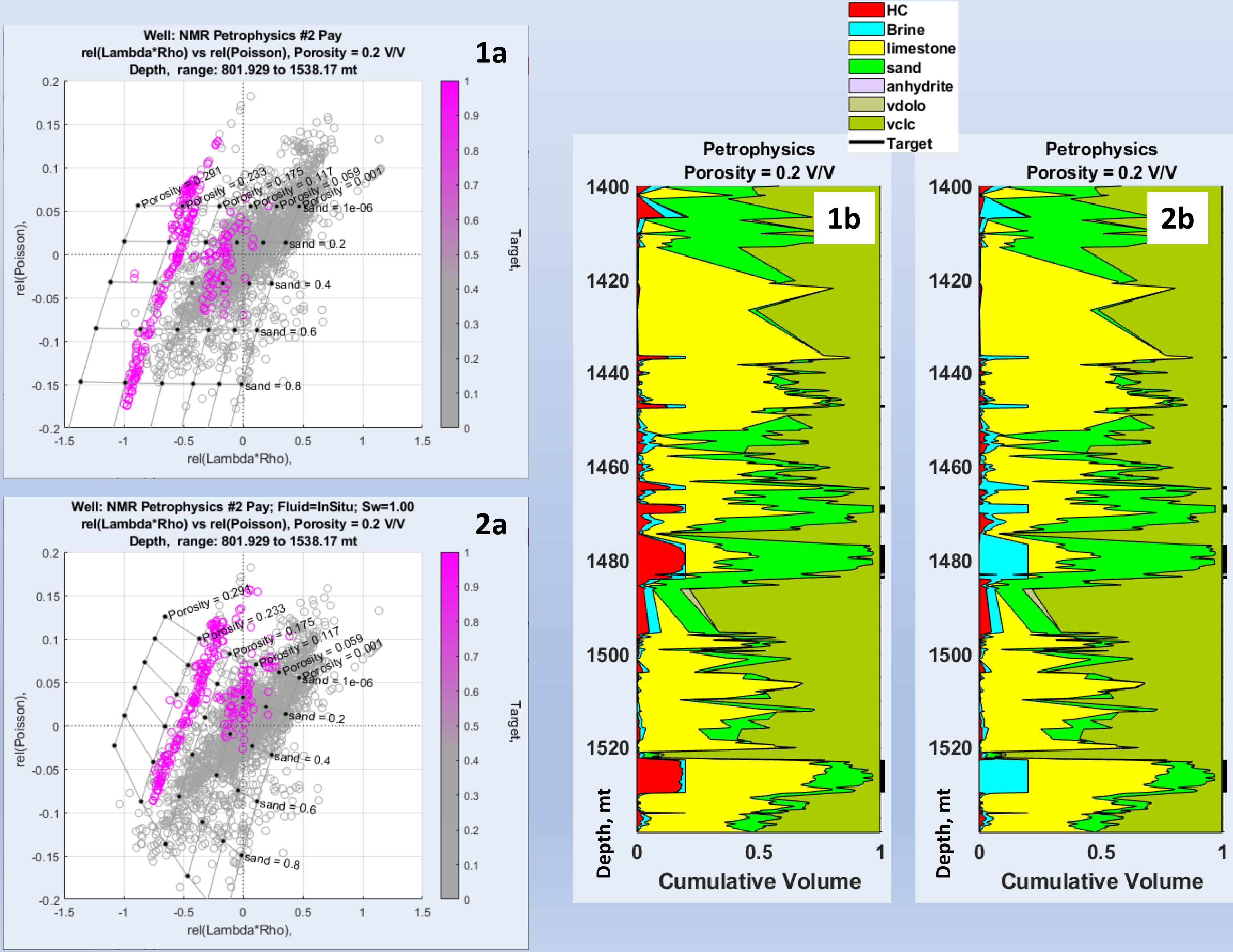
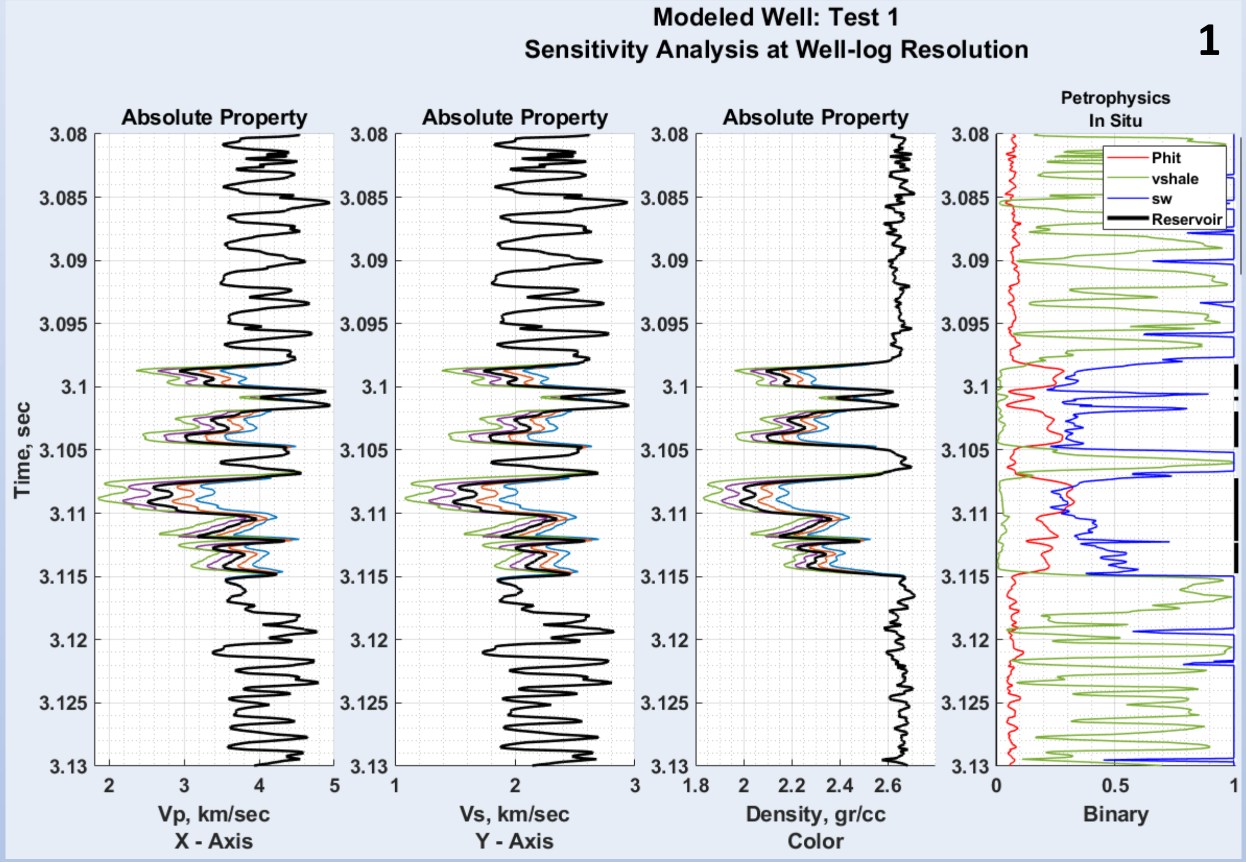


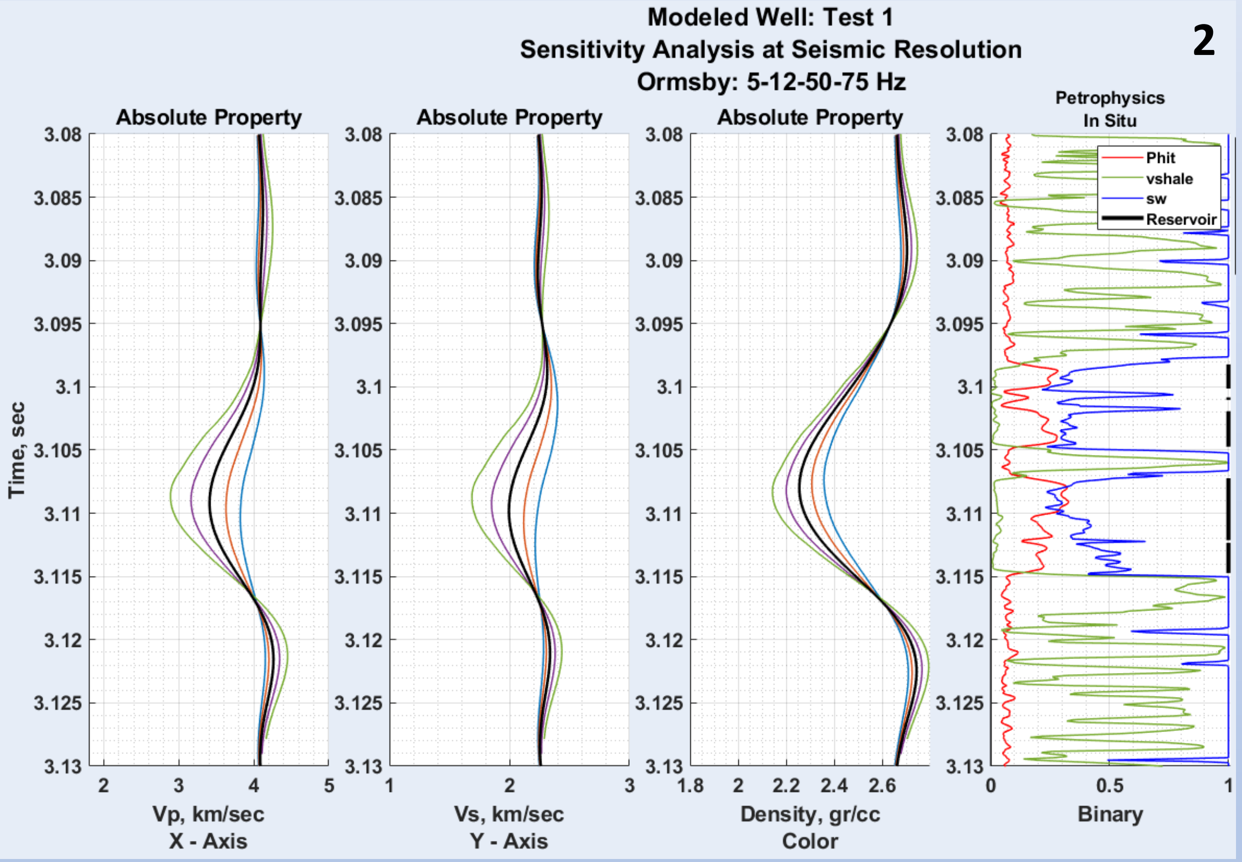
Figure 1a. Rock properties for a constant porosity of 0.2 V/V.

Figure 1b. Petrophysical evaluation corresponding to cross-plot 1a.

Figure 2a. Rock properties for a constant porosity of 0.2 V/V and $S_W = 1.0$.

Figure 2b. Petrophysical evaluation corresponding to cross-plot 2a.





Porosity modification at target flag

- Porosity = 80 % of in situ
- Porosity = 90 % of in situ
- Porosity = 100 % of in situ
- Porosity = 110 % of in situ
- Porosity = 120 % of in situ
- inSitu

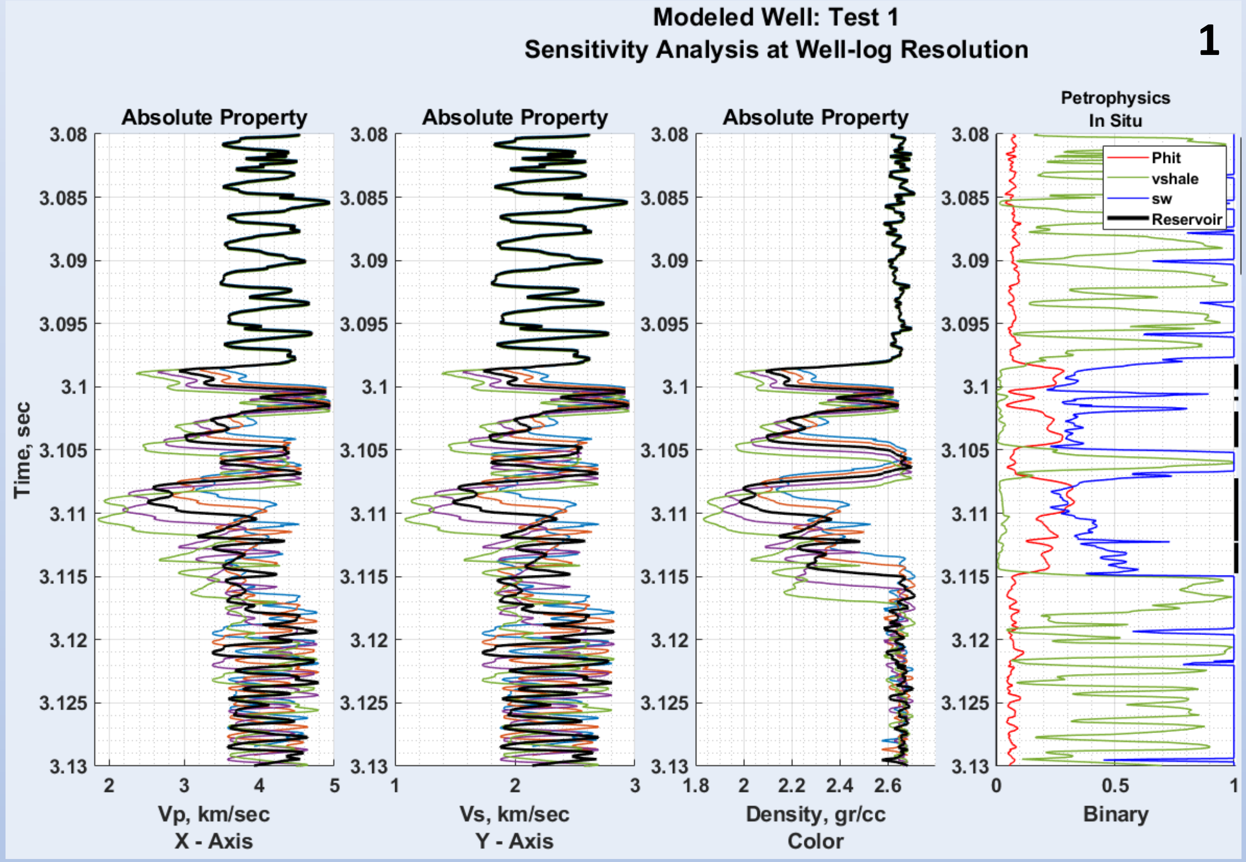
Sensitivity of rock properties (V_P , V_S and density) to changes in porosity

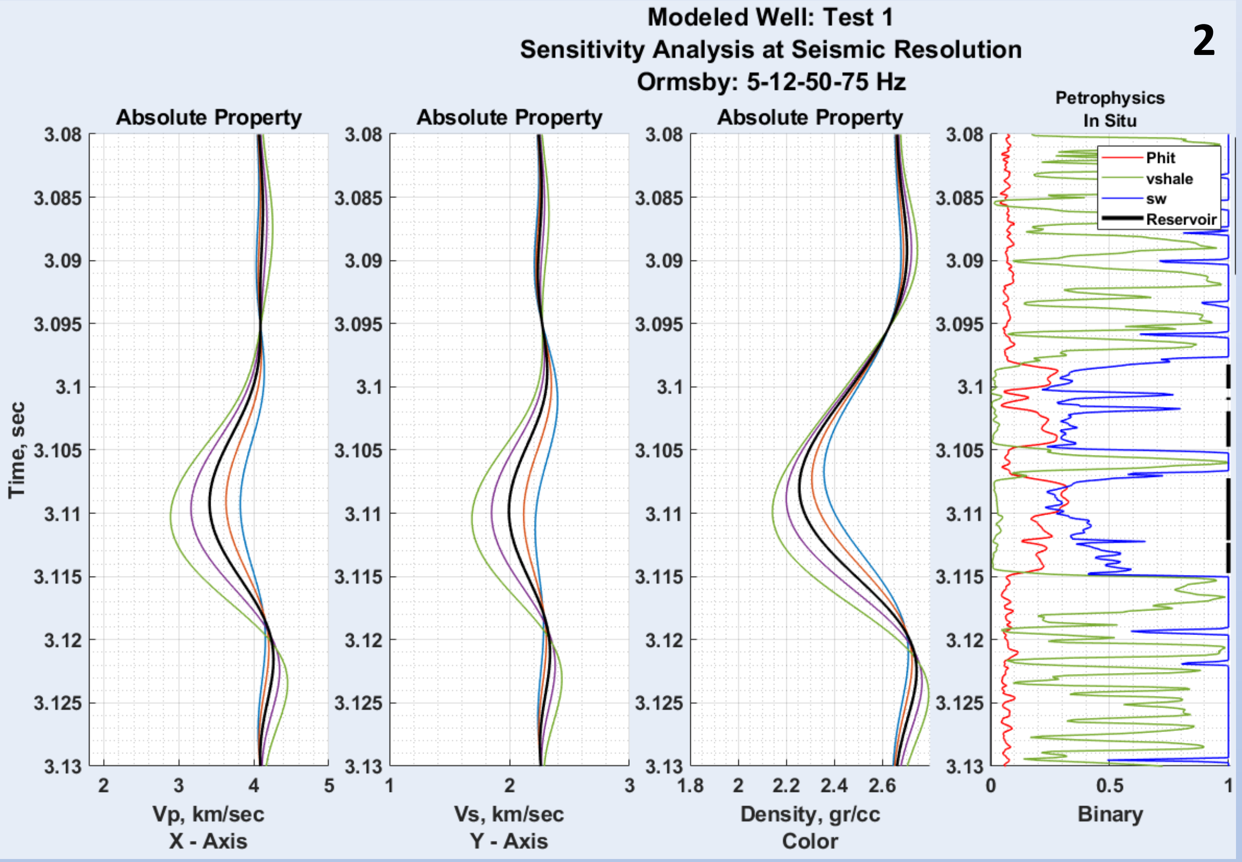
Two-way time is that of in-situ properties
Petrophysics shown correspond to in-situ properties

Figure 1. Analysis at well-log resolution

Figure 2. Analysis at seismic resolution

Compare to next slide





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Two-way time is that resultant after modifying porosity
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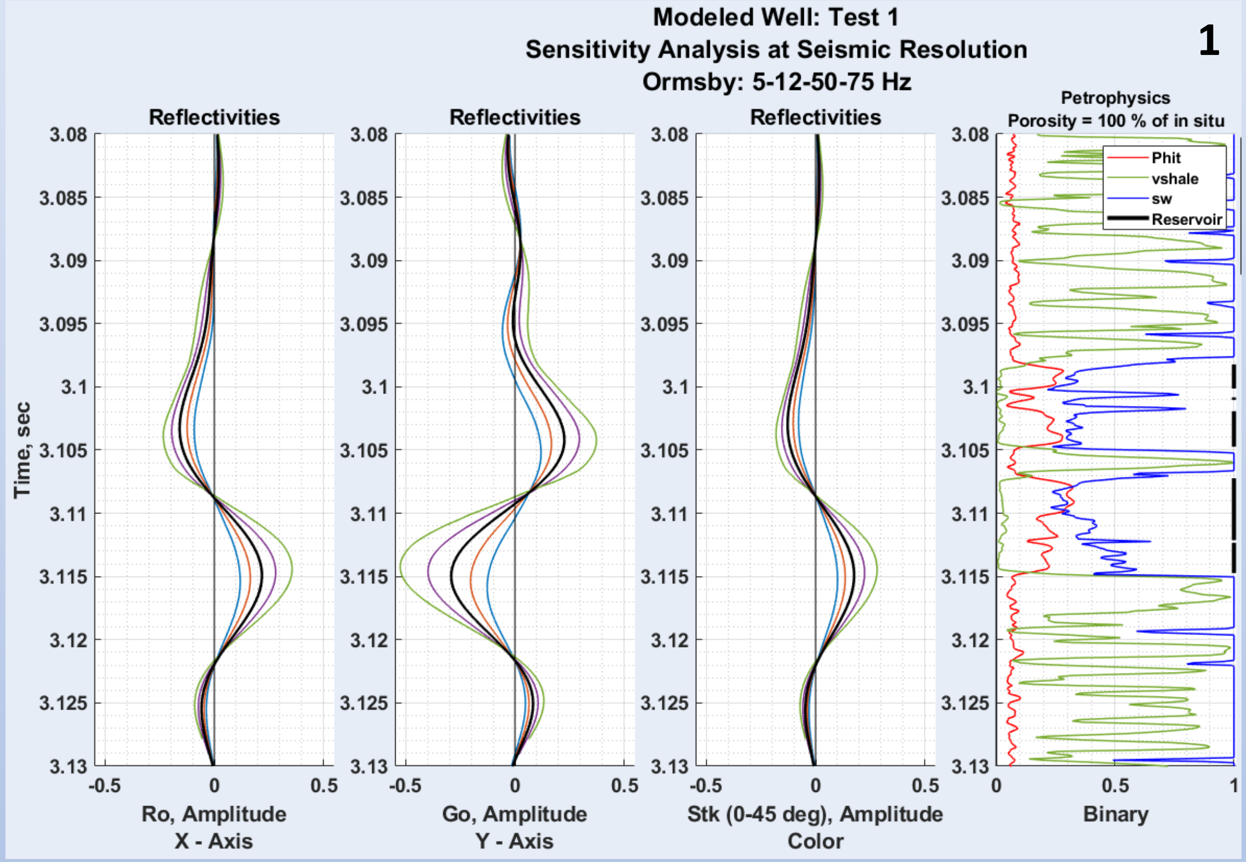
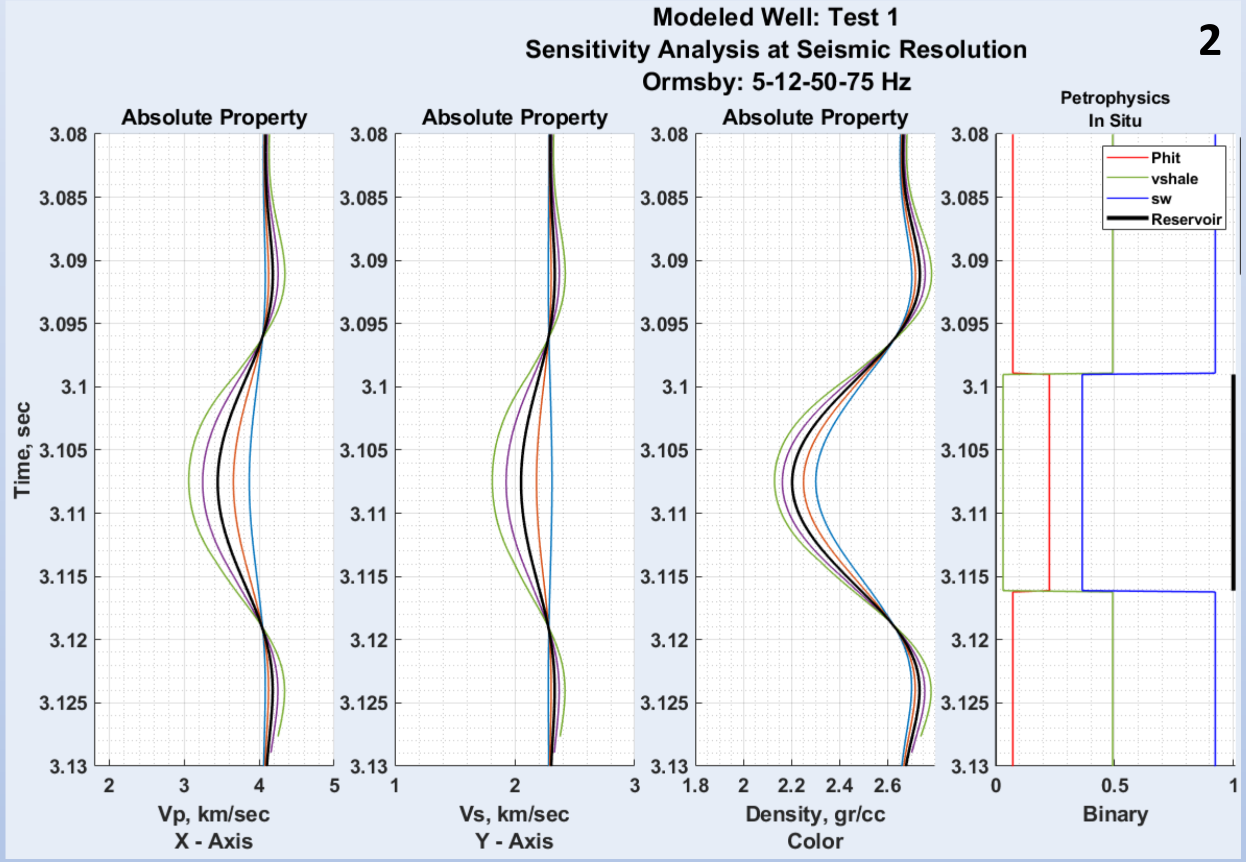
Figure 2. Analysis at seismic resolution

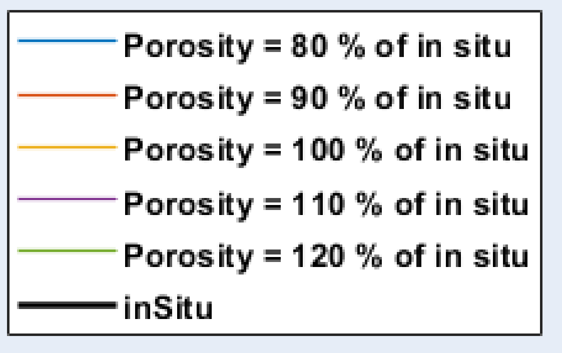
Compare to previous slide





Sensitivity of rock properties and reflectivities to changes in porosity

Porosity modification at target flag

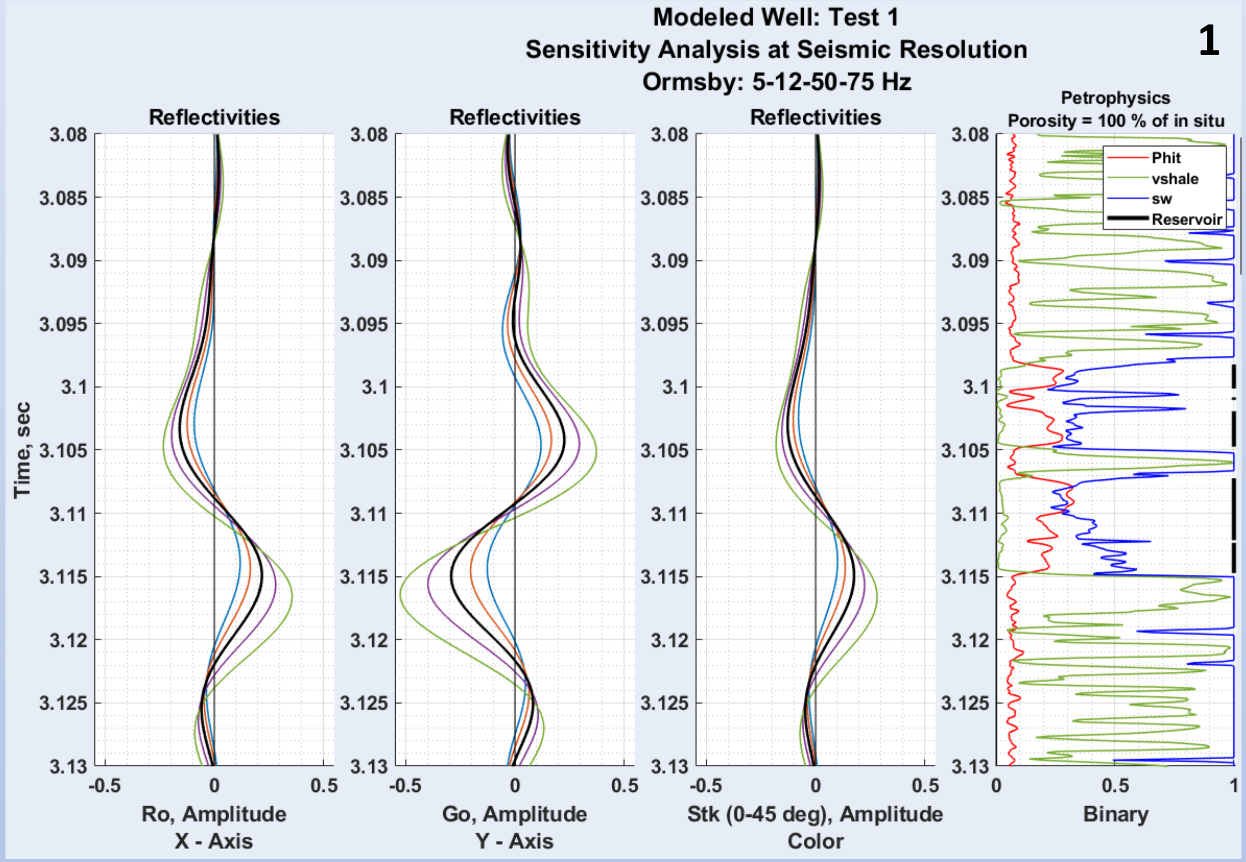


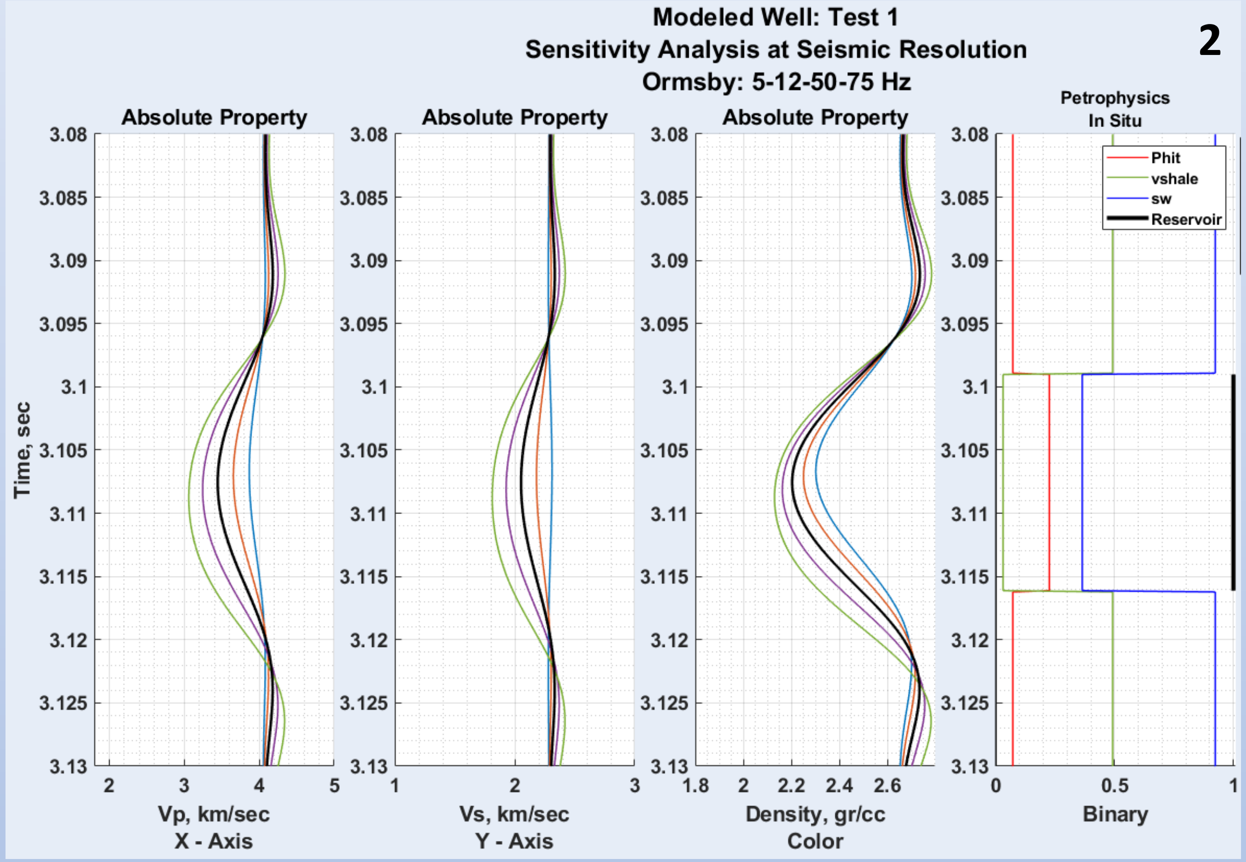
Two-way time is that of in-situ properties
Petrophysics shown correspond to in-situ properties

Figure 1. Analysis at seismic resolution – AVO attributes and stack

Figure 2. Thin bed analysis at seismic resolution - Rock properties (V_P , V_S and density)

Compare to next slide





Sensitivity of rock properties and reflectivities to changes in porosity

Porosity modification at target flag

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- Porosity = 90 % of in situ
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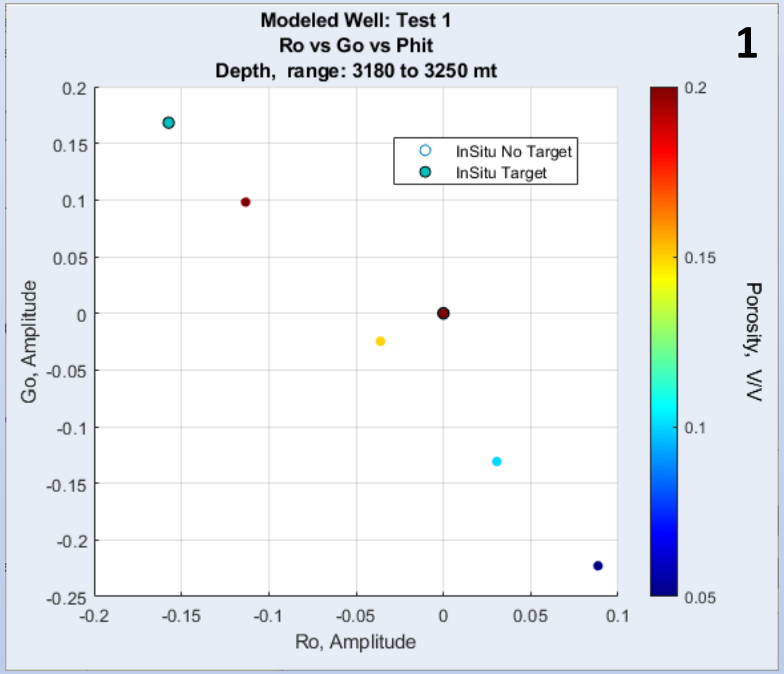
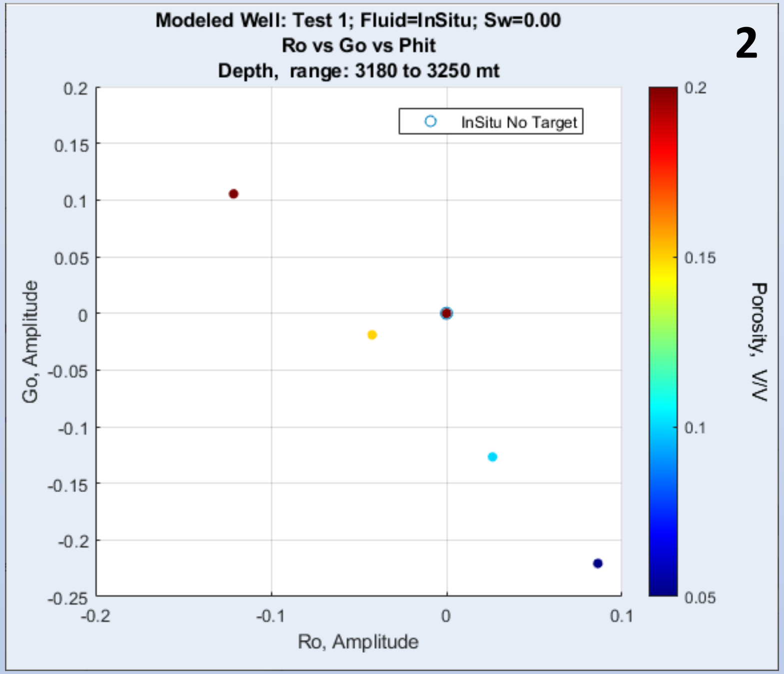
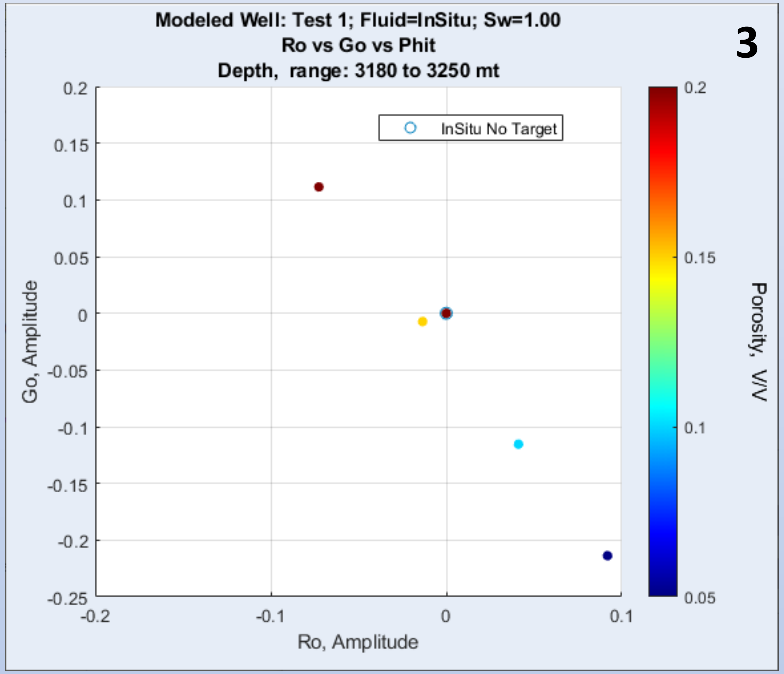
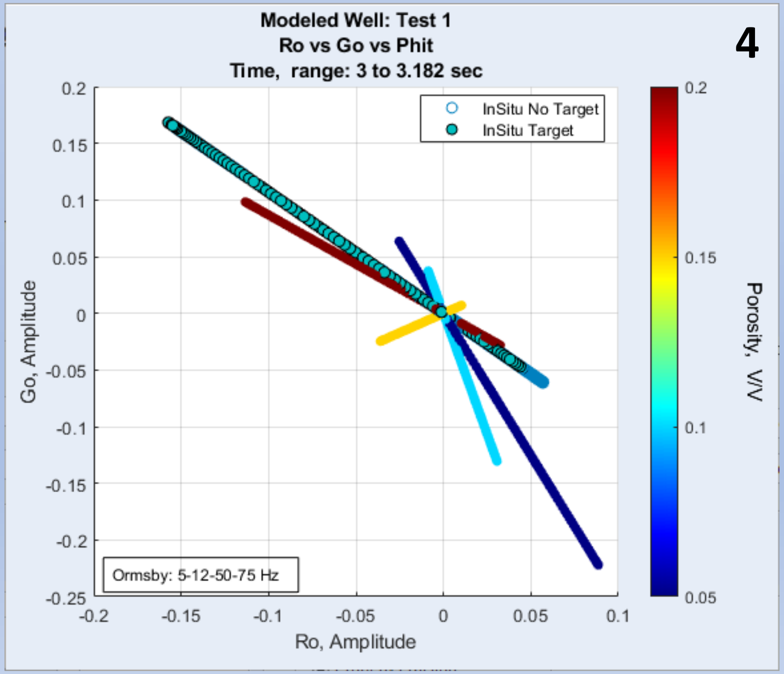
Compare to previous slide









Half-space AVO reflectivities

0.05 <= Porosity <= 0.2 :

Porosity increment = 0.05 V/V

AVO attributes are computed from average reservoir properties

Figure 1. In-situ

Figure 2. S_W = 0.0

Figure 3. S_W = 1.0

Figure 4. In-situ at seismic resolution

3D
Seismic – Petrophysical Modeling

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Seismic-Petrophysical Modeling

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- Objective

    - Create datasets in which well-data is perturbed in target interval(s), and synthetic seismic computed for the perturbed well data.

The pseudo well and synthetic seismic data created are used to evaluate/calibrate seismic inversions as well as to estimate seismic attributes' sensitivity to changes in petrophysical properties.

Seismic-Petrophysical Modeling

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- **Methodology**
  - Create a 3D volume of petrophysical properties from an evaluation in a well. Two of the properties are modified in inline and crossline directions (for example, porosity (ϕ), in inline direction and minerology in the cross-line direction).
  - Elastic Rock Properties (V_P, V_S) and density (ρ) are computed for each pseudo-well in the 3D volume.
  - Seismic attributes are computed in time or depth, and at well-log or seismic resolutions

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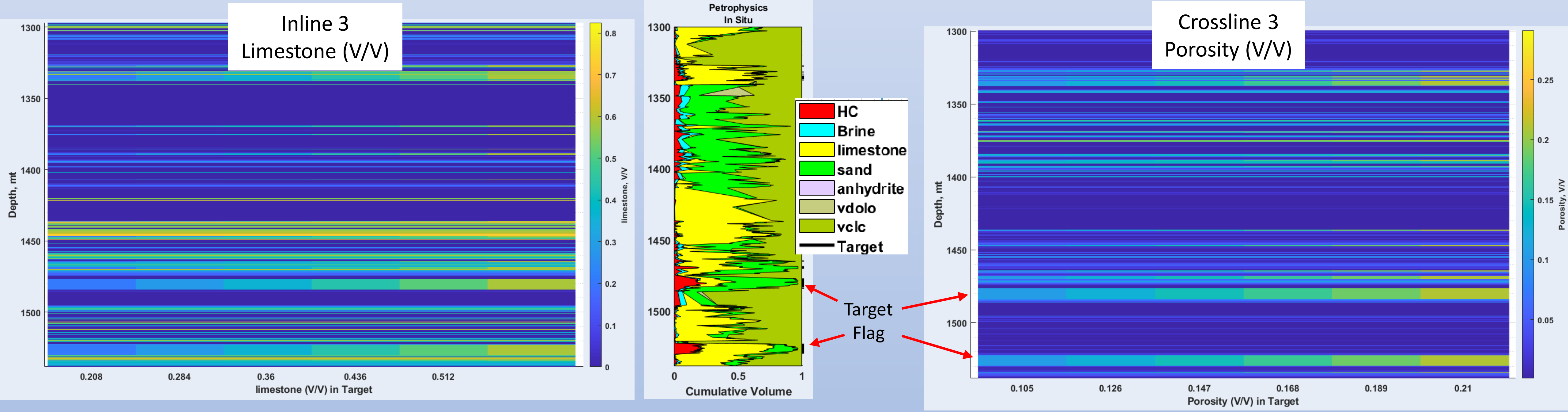
Seismic-Petrophysical Modeling



MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021 V/V
XLine 1 To 6 - limestone
From: 0.208 To: 0.586 By: 0.076 V/V

DISPLAY
ILine 3
Constant Porosity = 0.147 V/V
XLines From 1 To 6
limestone From: 0.208 To: 0.586 By: 0.076 V/V

The petrophysical evaluation (middle plot) is modified at the target flag to create a 3D volume of pseudo-wells.

In these plots porosity is modified in inline direction and limestone V/V is modified in cross-line direction.

MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021 V/V
XLine 1 To 6 - limestone
From: 0.208 To: 0.586 By: 0.076 V/V

DISPLAY
XLine 3
Constant limestone = 0.359 V/V
ILines From 1 To 6
Porosity From: 0.105 To: 0.211 By: 0.021 V/V

Seismic-Petrophysical Modeling

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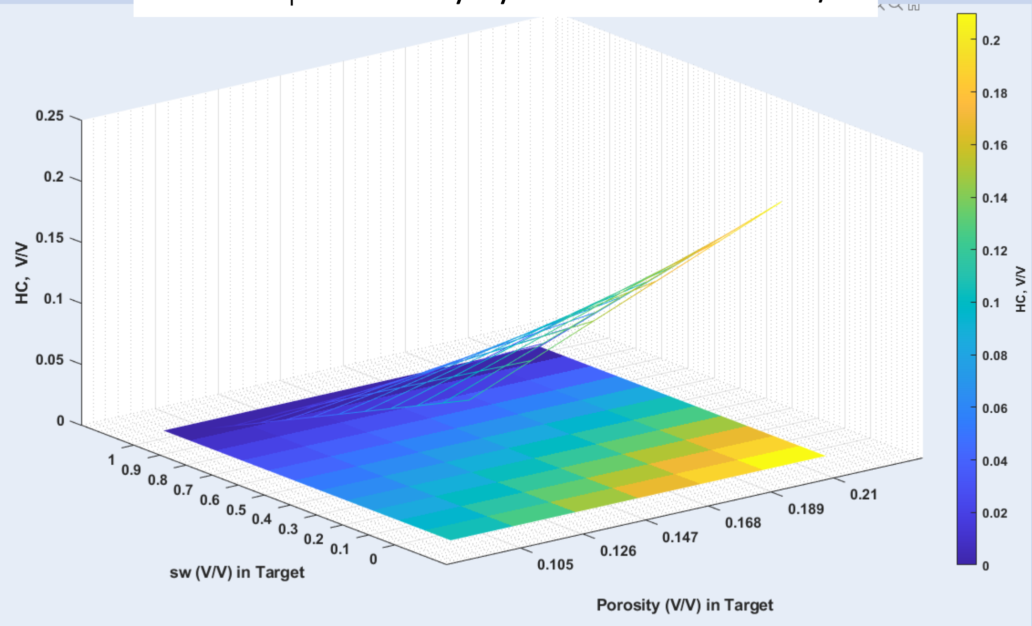
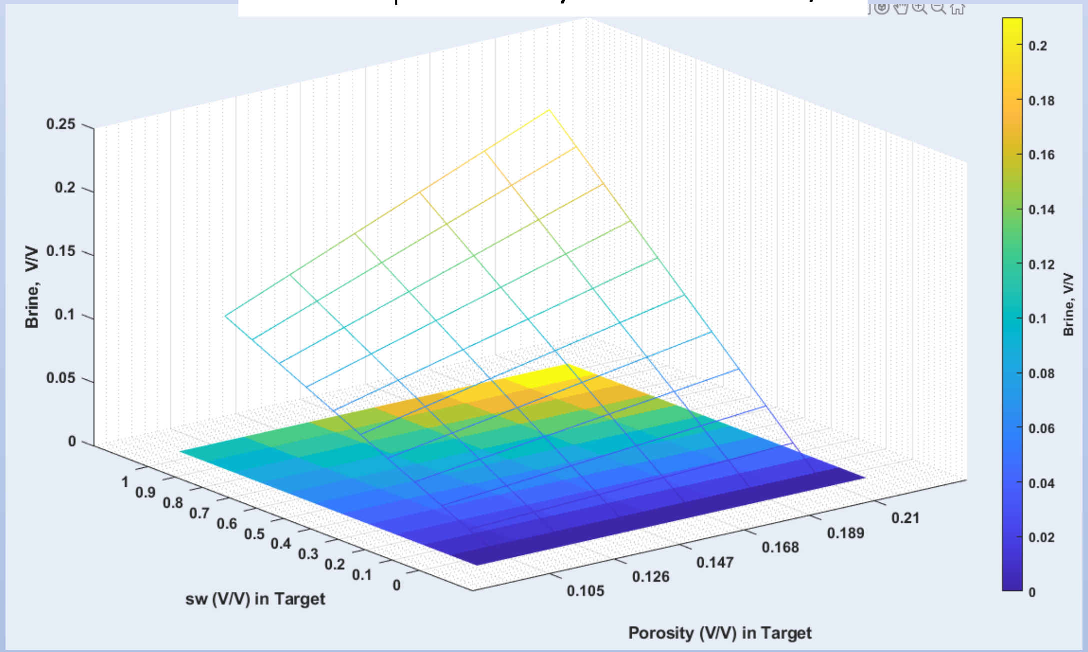
Sw and ϕ colored by hydrocarbon volume V/V



Sw and ϕ colored by brine volume V/V



MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021 V/V
XLine 1 To 11 - sw
From: 0 To: 1 By: 0.1 V/V

Horizontal Slice at : 1335, mt

Horizontal slices of a model in which porosity and water saturation (Sw) were modified.

The color in the plots show volume of hydrocarbon (V/V) at left and volume of Brine (V/V) at right.

MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021 V/V
XLine 1 To 11 - sw
From: 0 To: 1 By: 0.1 V/V

Horizontal Slice at : 1335, mt

Seismic-Petrophysical Modeling

TraceSeis Inc.
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- **Methodology**

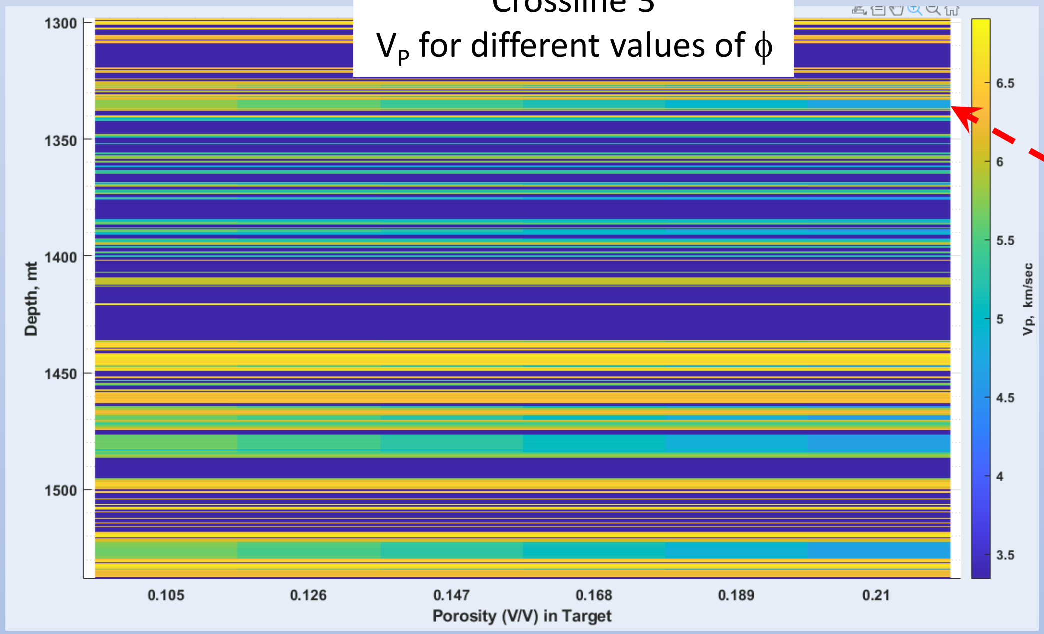
  - Create a 3D volume of petrophysical properties from an evaluation in a well. Two of the properties are modified in inline and crossline directions (for example, porosity (ϕ), in inline direction and minerology in the cross-line direction).

  - ***Elastic Rock Properties (V_P, V_S) and density (ρ) are computed for each pseudo-well in the 3D volume.***

  - Seismic attributes are computed in time or depth, and at well-log or seismic resolutions

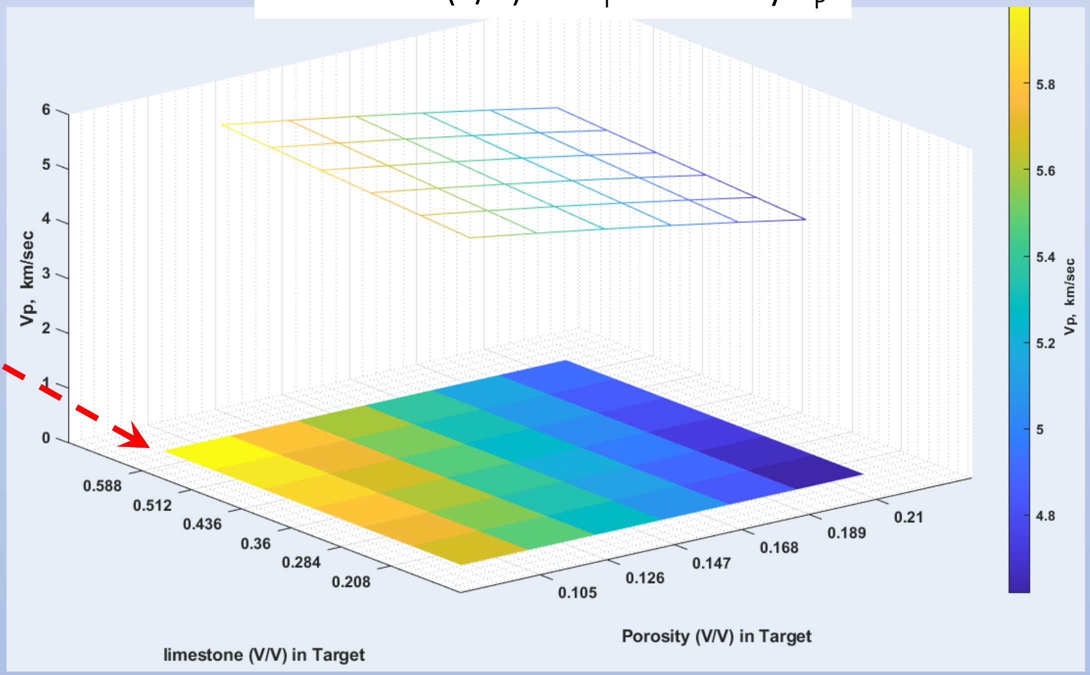
Seismic-Petrophysical Modeling

Crossline 3
V_P for different values of ϕ



Horizontal Slice at 1335 mts

Limestone (V/V) and ϕ colored by V_P



MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021 V/V
XLine 1 To 6 - limestone
From: 0.208 To: 0.586 By: 0.076 V/V

DISPLAY
XLine 3
Constant limestone = 0.359 V/V
ILines From 1 To 6
Porosity From: 0.105 To: 0.211 By: 0.021 V/V

3D volumes of V_P, V_S and density (ρ) are computed from the modified petrophysics volumes.

The left image shows the V_P section in which limestone is kept constant at 0.359 V/V and porosity changes from 0.105 V/V to 0.211 V/V by 0.076 increments

MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021
V/VXLine 1 To 6 - limestone
From: 0.208 To: 0.586 By: 0.076 V/V

Horizontal Slice at : 1335, mt

Seismic-Petrophysical Modeling

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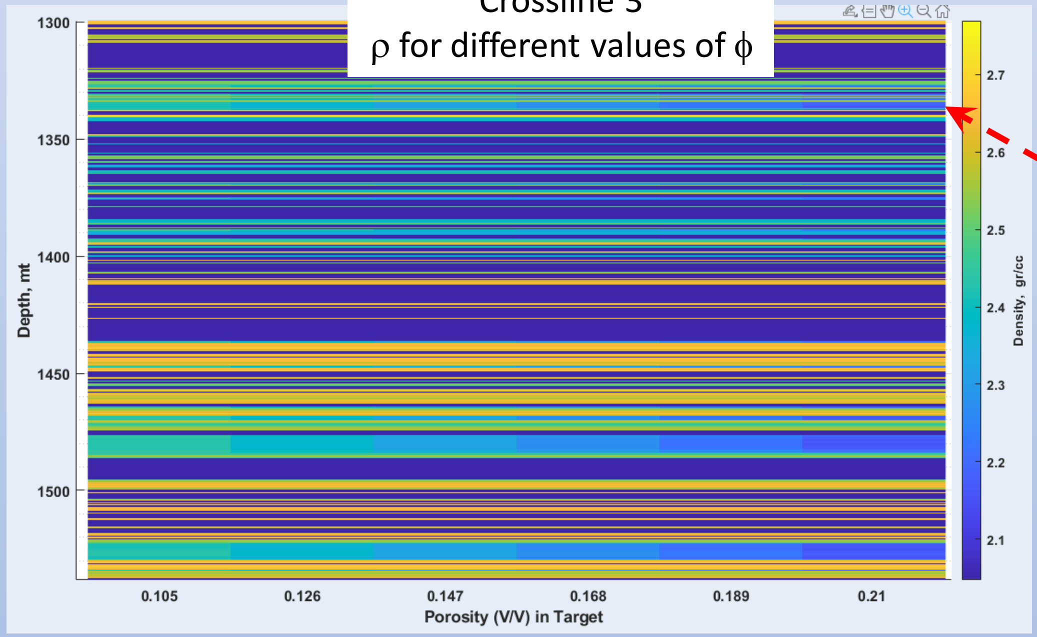
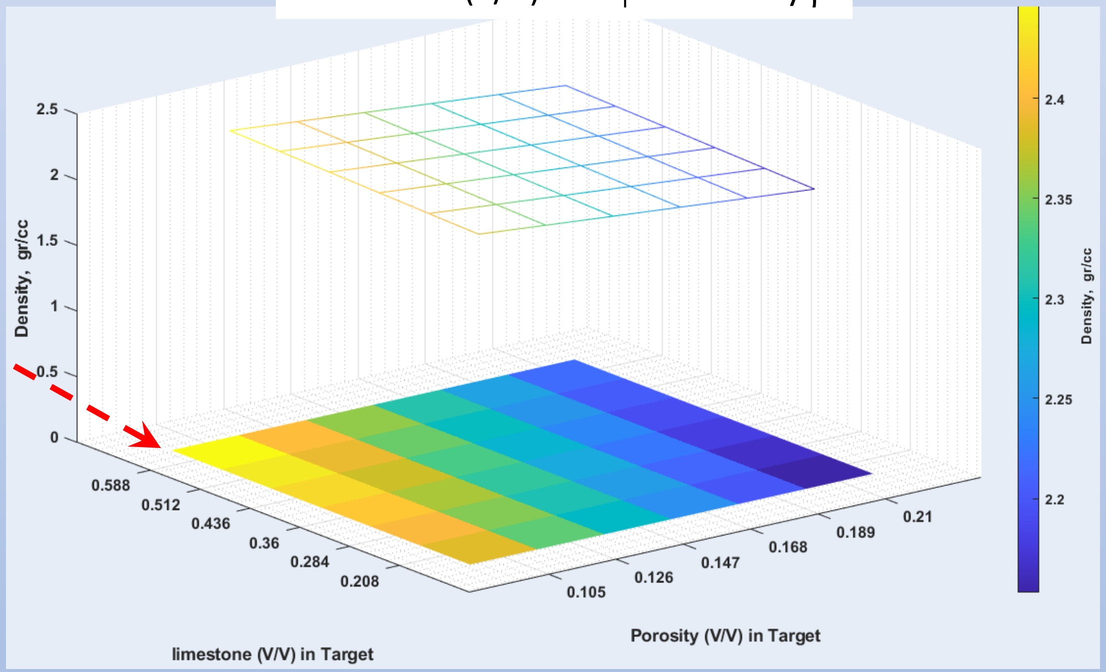


Horizontal Slice at 1335 mts



MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021 V/V
XLine 1 To 6 - limestone
From: 0.208 To: 0.586 By: 0.076 V/V

DISPLAY
XLine 3
Constant limestone = 0.359 V/V
ILines From 1 To 6
Porosity From: 0.105 To: 0.211 By: 0.021 V/V

The left image shows the ρ section in which limestone is kept constant at 0.359 V/V and porosity changes from 0.105 V/V to 0.211 V/V by 0.021 increments

MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021 V/VXLine 1 To 6 - limestone
From: 0.208 To: 0.586 By: 0.076 V/V

Horizontal Slice at : 1335, mt

Seismic-Petrophysical Modeling

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- **Methodology**

  - Create a 3D volume of petrophysical properties from an evaluation in a well. Two of the properties are modified in inline and crossline directions (for example, porosity (ϕ), in inline direction and minerology in the cross-line direction).

  - Elastic Rock Properties (V_P, V_S) and density (ρ) are computed for each pseudo-well in the 3D volume.

  - ***Seismic attributes are computed in time or depth, and at well-log or seismic resolutions***

Seismic-Petrophysical Modeling

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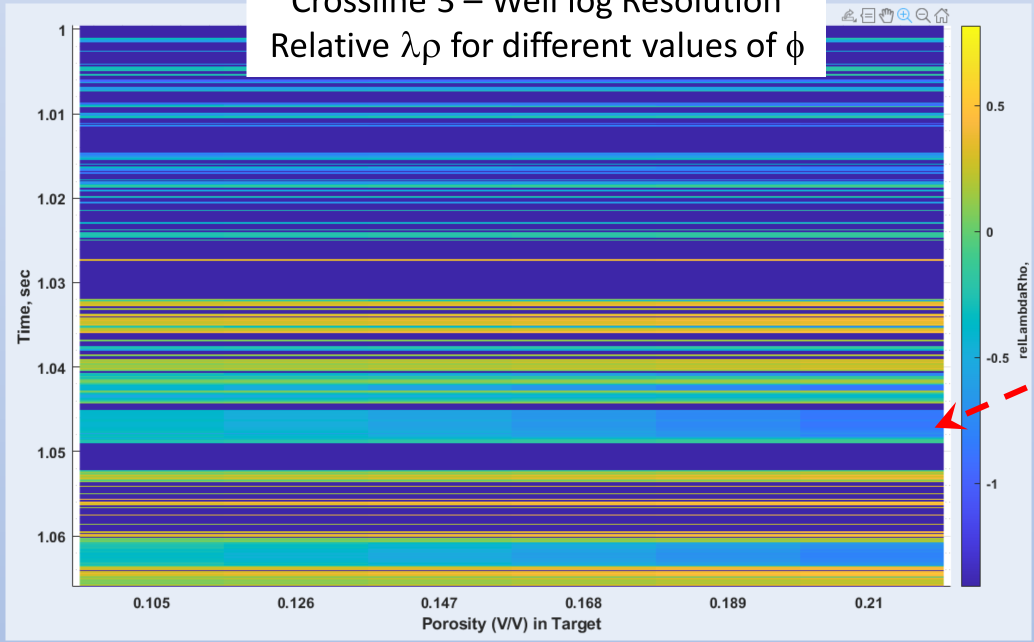
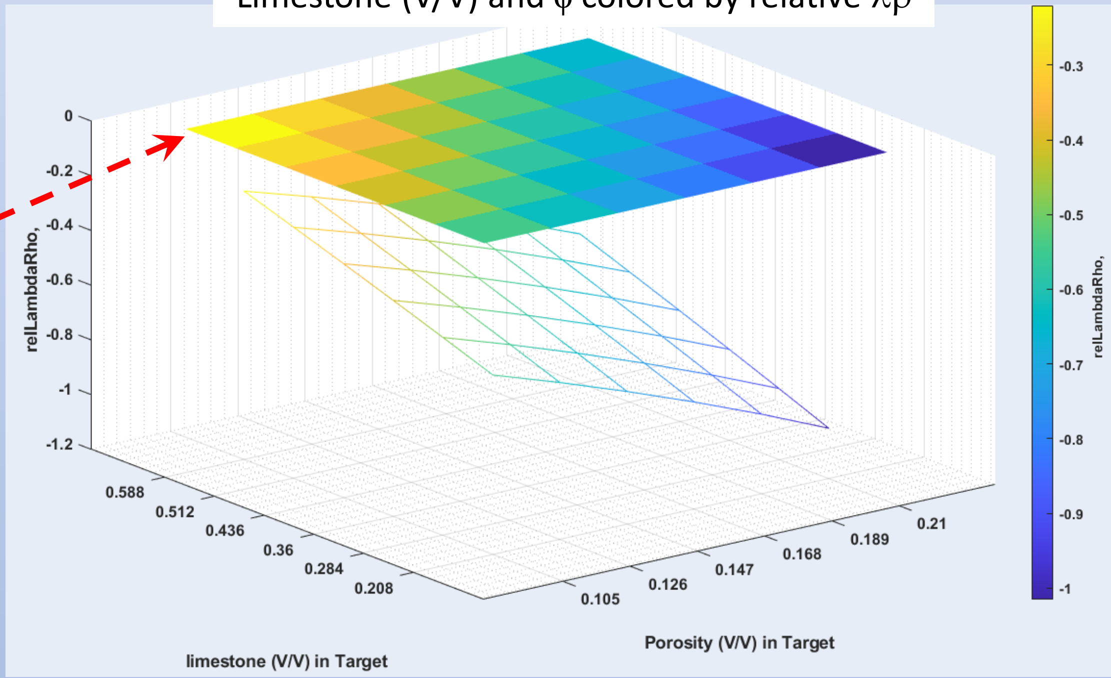
Crossline 3 – Well log Resolution
Relative λρ for different values of ϕ



Horizontal Slice at 1.047 sec

Limestone (V/V) and ϕ colored by relative λρ



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XLine 3
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ILines From 1 To 6
Porosity From: 0.105 To: 0.211 By: 0.021 V/V

Data in time at well-log Resolution

The left image shows the relative λρ section in which limestone is kept constant at 0.359 V/V and porosity changes from 0.105 V/V to 0.211 V/V by 0.021 increments

MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021
V/VXLine 1 To 6 - limestone
From: 0.208 To: 0.586 By: 0.076 V/V

Horizontal Slice at : 1.047, sec

Seismic-Petrophysical Modeling

TraceSeis Inc.
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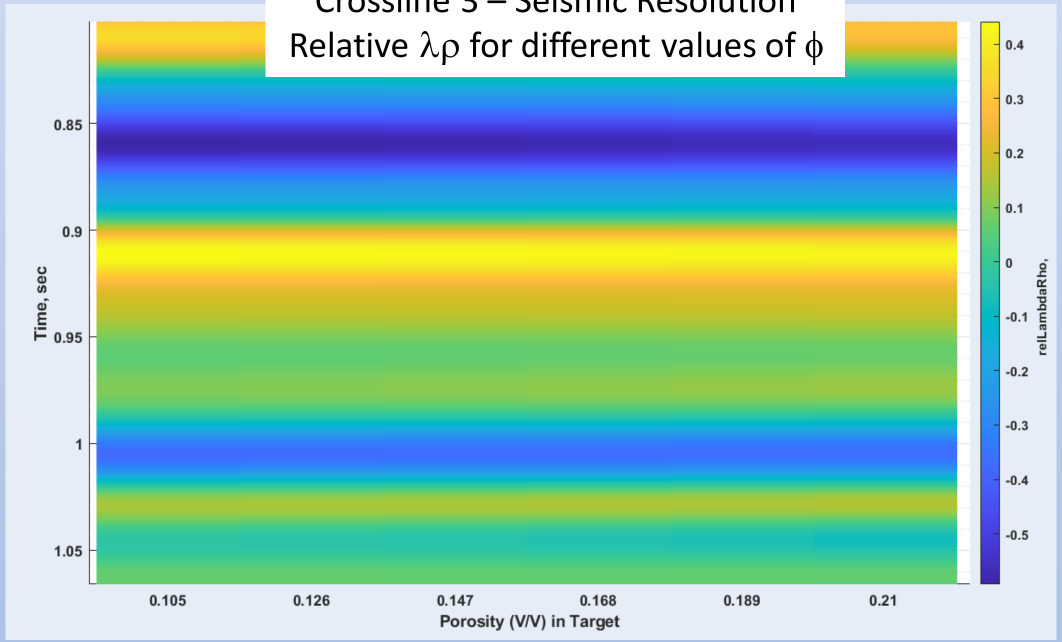
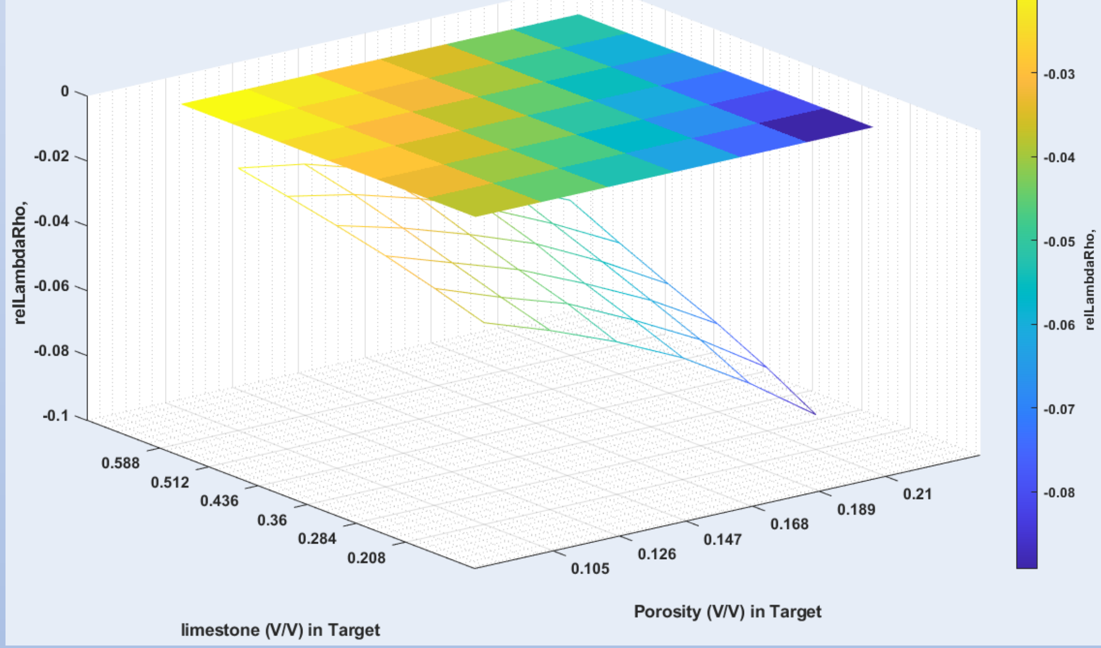
Crossline 3 – Seismic Resolution
Relative λρ for different values of ϕ



Limestone (V/V) and ϕ colored by relative λρ



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Inline 1 To 6 - Porosity
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XLine 1 To 6 - limestone
From: 0.208 To: 0.586 By: 0.076 V/V

DISPLAY
XLine 3
Constant limestone = 0.359 V/V
ILines From 1 To 6
Porosity From: 0.105 To: 0.211 By: 0.021 V/V

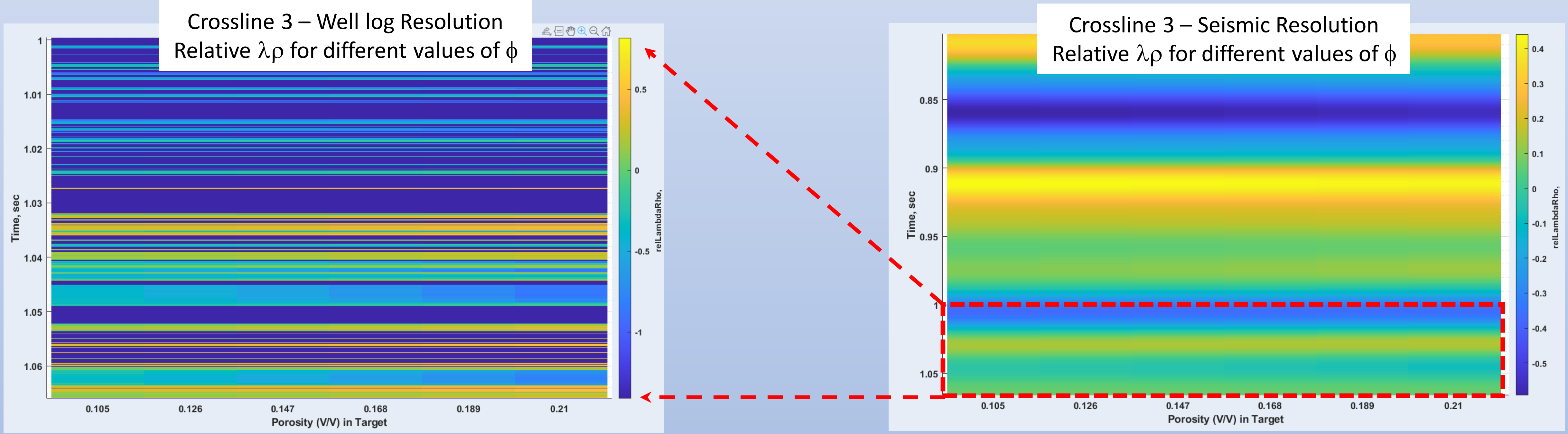
Data in time at seismic Resolution

The left image shows, in seismic resolution, the relative λρ section in which limestone is kept constant at 0.359 V/V and porosity changes from 0.105 V/V to 0.211 V/V by 0.021 increments.
Note the difference in time plotted from the previous slide.
Note the difference in attribute values from previous slide.

MODEL
Inline 1 To 6 - Porosity
From: 0.105 To: 0.211 By: 0.021
V/VXLine 1 To 6 - limestone
From: 0.208 To: 0.586 By: 0.076 V/V

Horizontal Slice at : 1.047, sec

Seismic-Petrophysical Modeling



MODEL
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Porosity From: 0.105 To: 0.211 By: 0.021 V/V

Data in time at seismic and well-log resolutions

The data plotted in time in previous images have different time scales for the well-log resolution (from 1.000 to 1.066 sec) and seismic resolution (0.8 t0 1.066 sec)

MODEL
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Porosity From: 0.105 To: 0.211 By: 0.021 V/V

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SeisMod

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