

# **Building Better Models: Toward Complete Integration of Well-Log Data Interpretation with 3D Reservoir Models\***

**Valery Polyakov<sup>1</sup>, Dzevat Omeragic<sup>2</sup>, R. Kocian, Sushil Shetty<sup>2</sup>, Benoit Brot<sup>2</sup>, Tarek Habashy<sup>2</sup>, Arathi Mahesh<sup>6</sup>, Torsten Friedel<sup>5</sup>, Torbjørn Vik<sup>3</sup>, and Tor Livar Flugsrud<sup>4</sup>**

Search and Discovery Article #40919 (2012)\*\*

Posted April 23, 2012

\*Adapted from oral presentation at GEO-2010, 10<sup>th</sup> Middle East Geosciences Conference and Exhibition, Manama, Bahrain, March 4-7, 2012

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## **Abstract**

We present an environment for high-angle and horizontal well evaluation integrated with reservoir geological models. It provides access to advanced 3D electromagnetic modeling algorithms for interpretation of resistivity measurements in complex 3D scenarios, going beyond the conventional layered-media models used for vertical and deviated wells. The environment is based on web services and includes high-performance computing (HPC) infrastructure enabling efficient running of modeling codes remotely, using all available computing resources (PC clusters, Grids or Clouds). The 3D well log modeling is embedded into a geomodeling package as a plug-in, thus enabling the interpretation of resistivity tool responses based on the underlying 3D reservoir model, by linking it to the parallelized simulators. The information inferred from the well logs is used in turn to fine-tune the 3D pillar grid-based reservoir model.

The system has been deployed in a giant carbonate field study to interpret hundreds of horizontal wells with varying extents and encompassing data from various wireline and LWD tools. The reservoir model was built using seismic and vertical well data. The results of log interpretation were propagated as a change to the pillar grid model. Examples demonstrate model refinement in a 2D cross-section by changing the dip and properties laterally to match the resistivity tool responses, and constructing a single model to match multiple log data acquired in three horizontal wellbores in close proximity.

The integrated workflow used in the process, from extraction of the reservoir model near the wellbore, to interactive model editing, such as structural updates or property adjustment, to the final stage of propagating changes made in a 2D “curtain” cross-section of the geomodel pillar grid back to the 3D reservoir model, yielded substantial efficiency gains. Saturation modeling on the scale of this case study had not been attempted before, and application of this new technology was the key to the successful execution of this study.

The new approach is essential for the interpretation of new-generation deep directional resistivity tools that are sensitive to the structure on the reservoir scale. It maximizes the value of log measurements by incorporating log information into the geomodels. Together with web services-based HPC simulation infrastructure, the system offers an unprecedented agility in formation evaluation and geomodel refinement process.

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*Excellence in Execution*

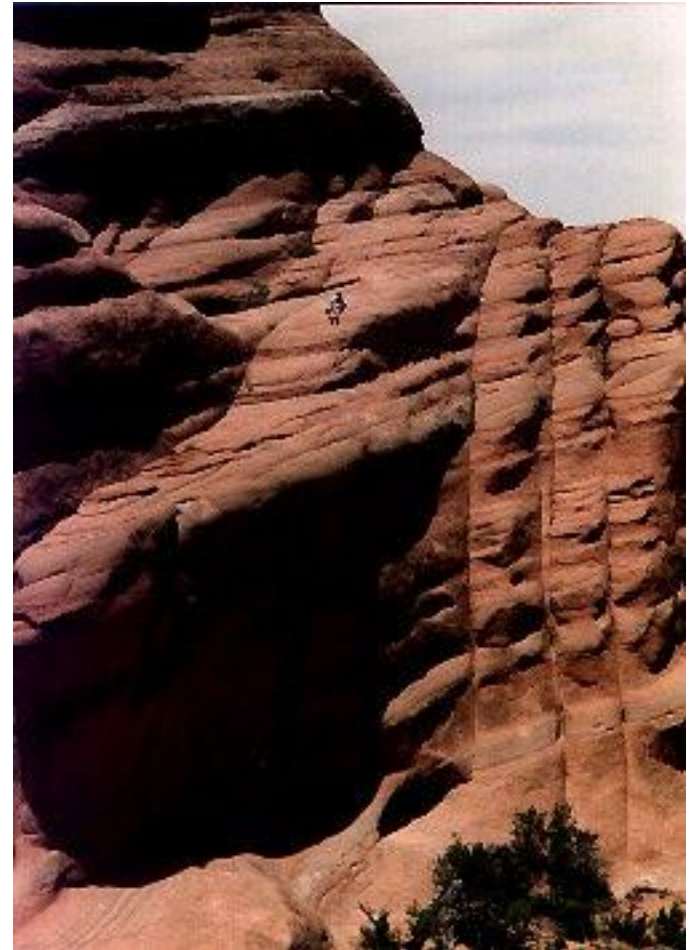
**Schlumberger**

# Outline

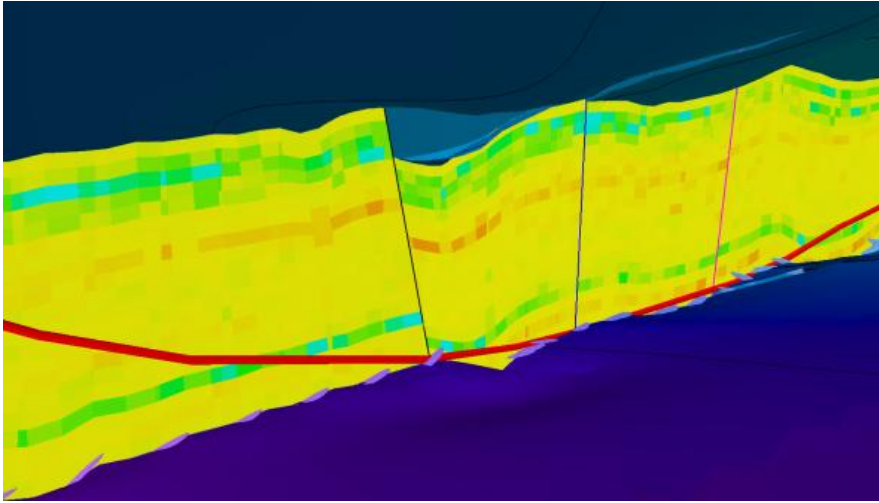
- Motivation and Challenges
- Reservoir Level Interpretation Workflow
- HPC Environment for High Angle/Horizontal Wells Integrated with Geomodeling
- Automated Update of Geomodels from Logs Interpretation
- Conclusions

# Motivation

- Capture reservoir heterogeneities in sub-seismic scale → improve accuracy of reservoir production estimates
- Reduce uncertainties in HA/HZ logs interpretation
- Enable full integration with Geomodels
  - Single model for reservoir simulation and well placement
  - Fully automated model update to ensure consistency and eliminate manual labor



# Challenges of Log Interpretation in HA/HZ Wells and 3D Well Placement



## Model Complexities

- Lateral variation (lithology, structure, fluid, invasion)
- $\alpha$  and  $\beta$  for all surfaces and cells
- Faults and fractures

## Response Complexities

- Coupling of bed boundary with faults, X-bedding, invasion, fractures, ...

## Computational

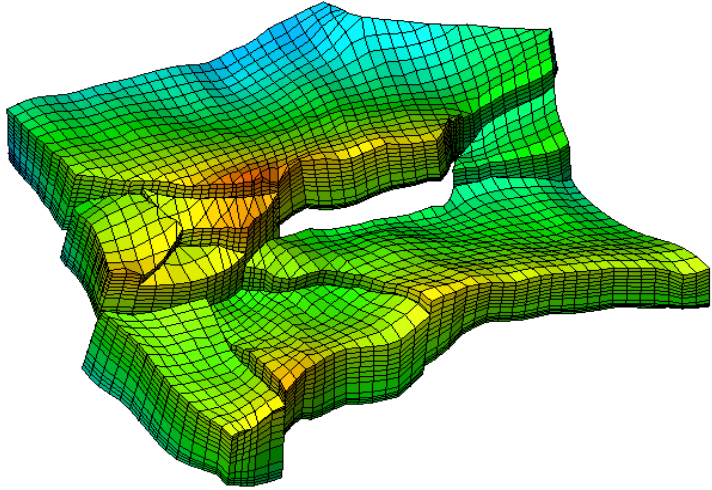
- Modeling and inversion algorithms

## Interpretation

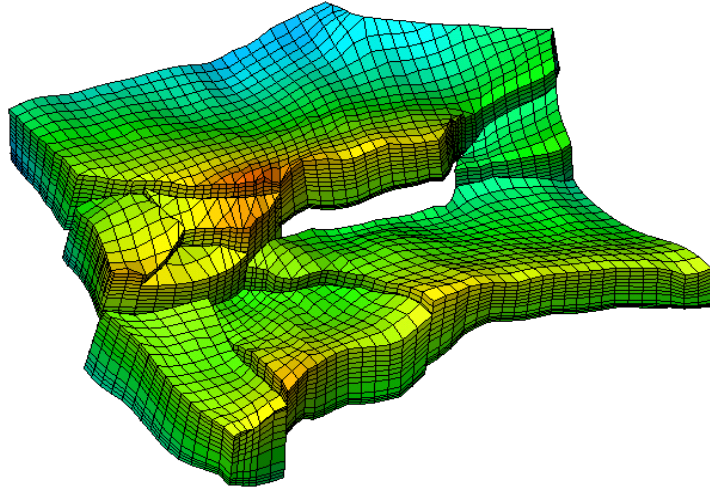
- Multi-measurements integration
- Integration with reservoir geomodel

**Physics-based log modeling is a must!**

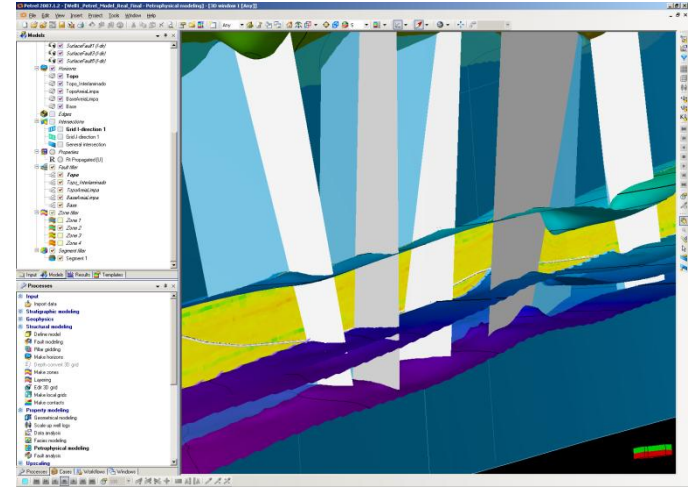
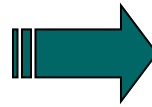
# 3D Reservoir Level Interpretation Workflow



# 3D Reservoir Level Interpretation Workflow

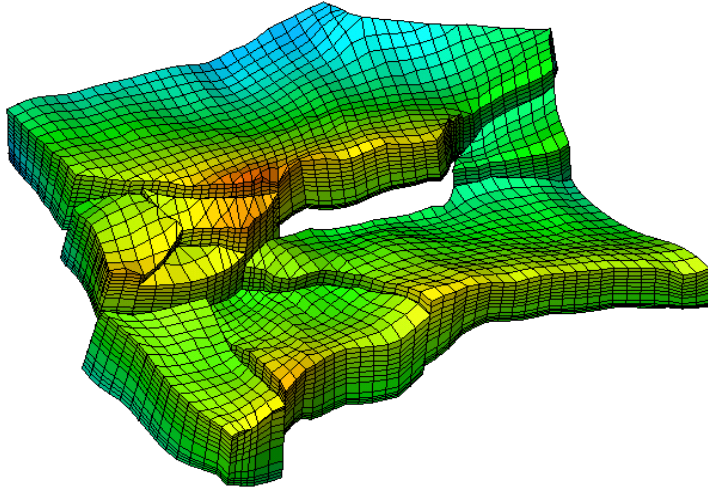


Model  
extraction

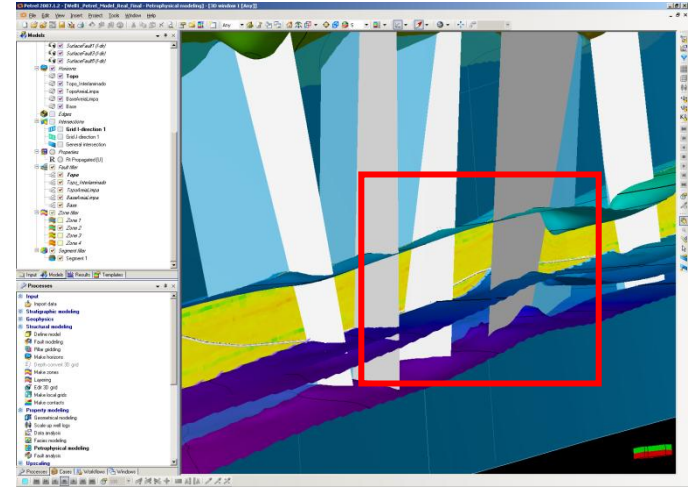
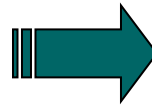




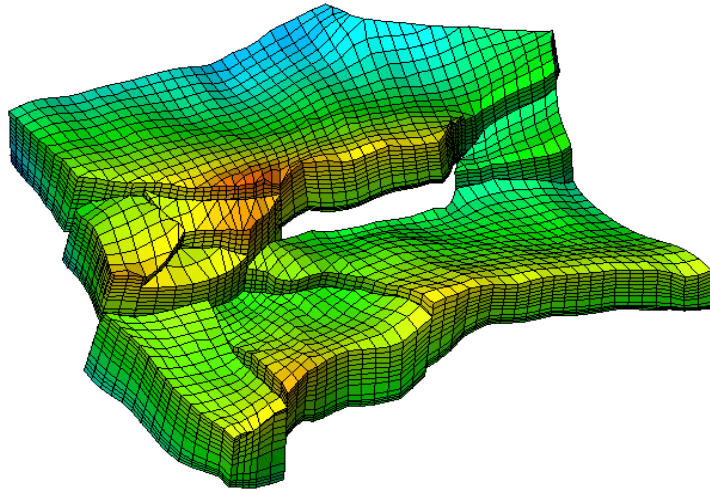
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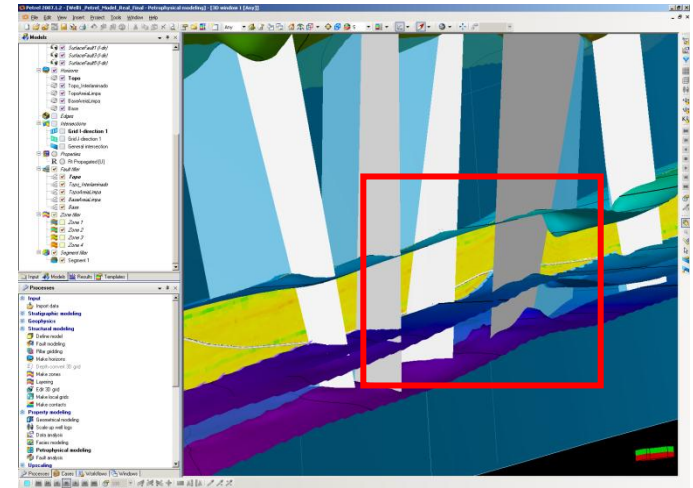
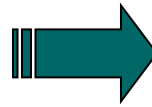
Model  
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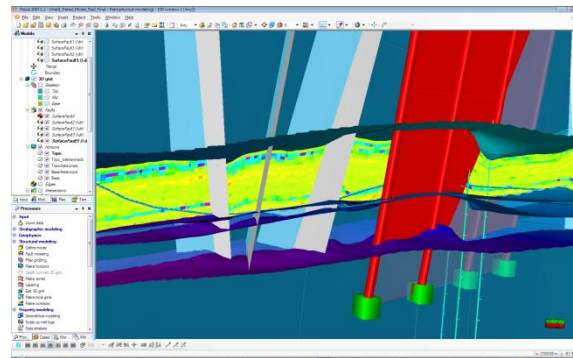
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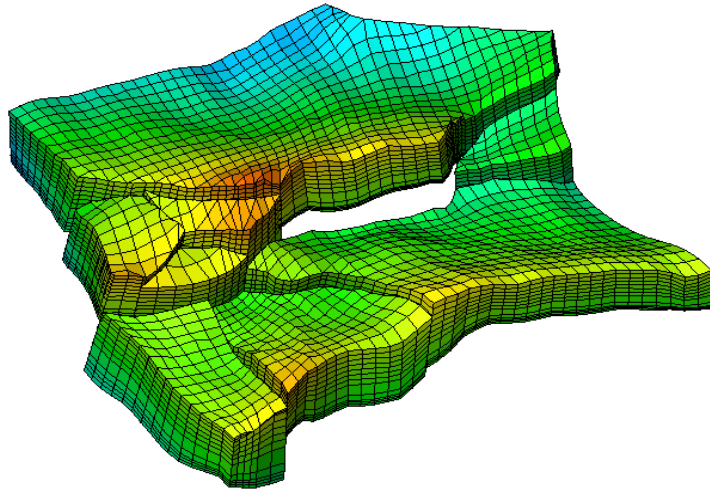
Model  
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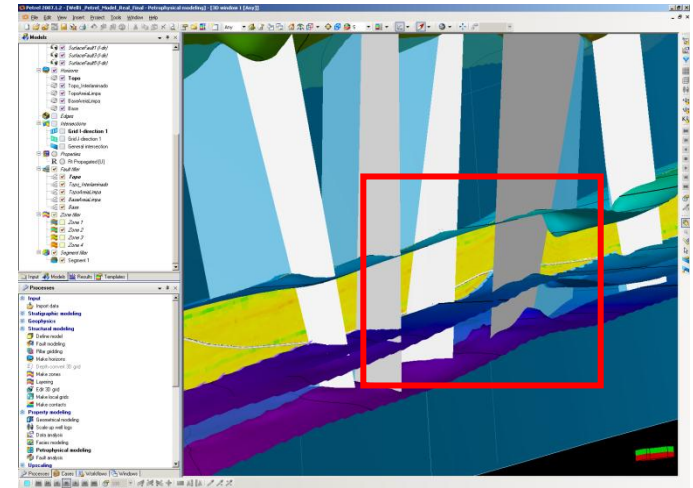
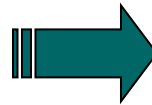
Parameterization  
Modeling & Inversion



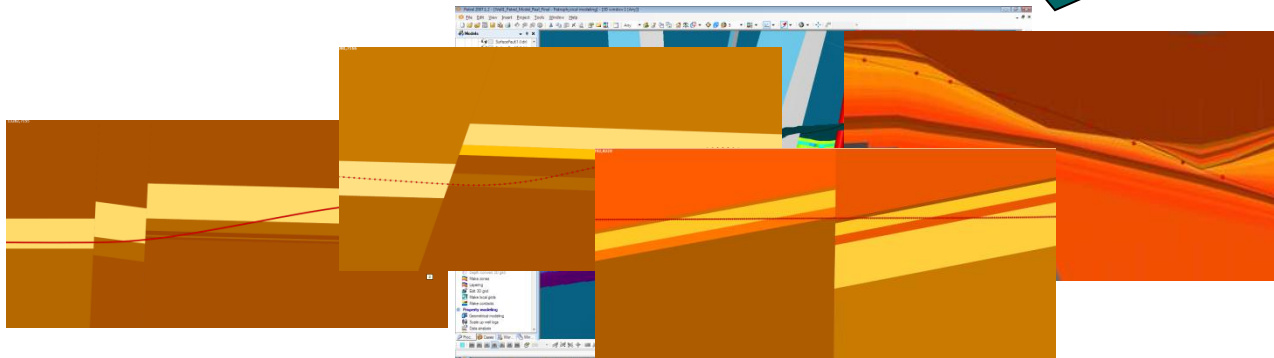
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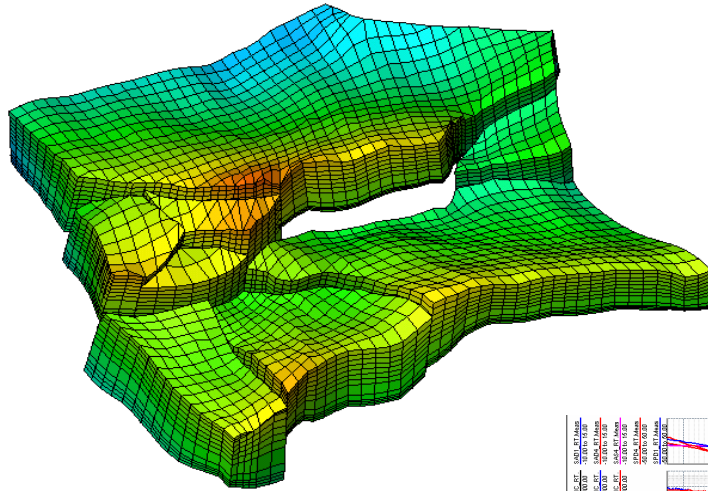
Model  
extraction



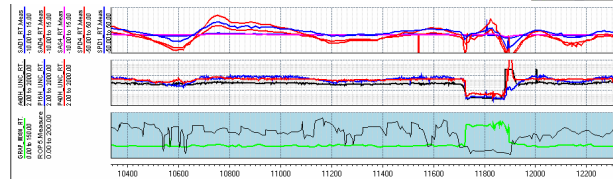
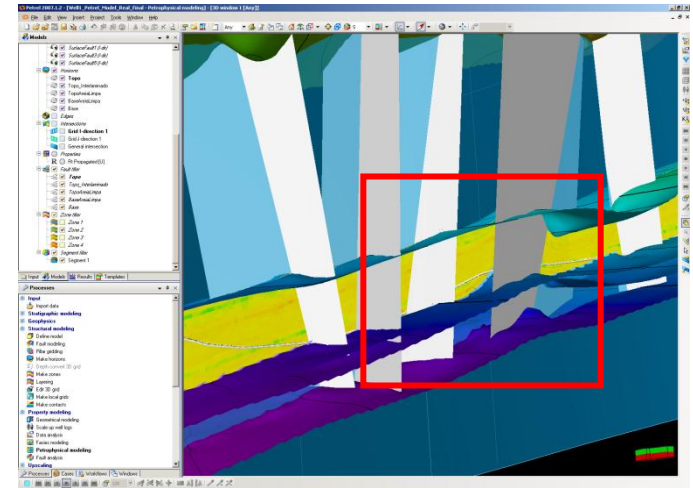
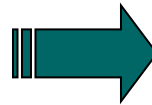
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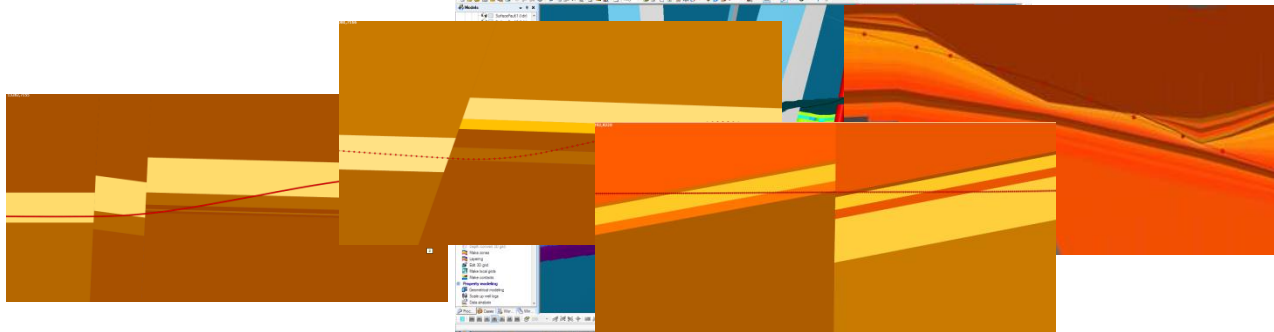
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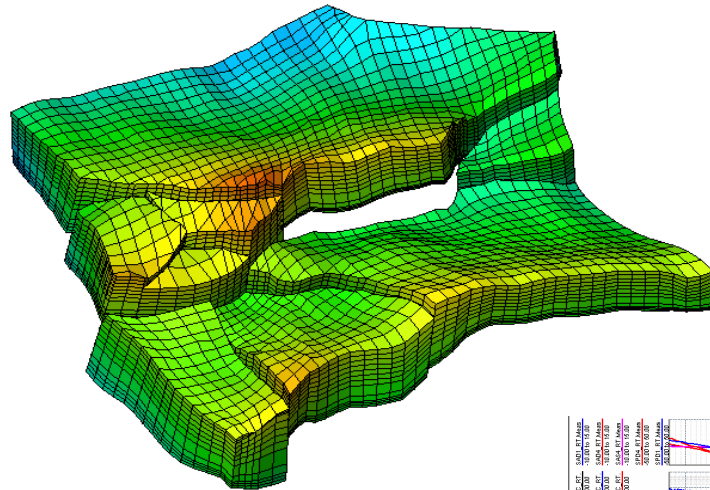
Model  
extraction



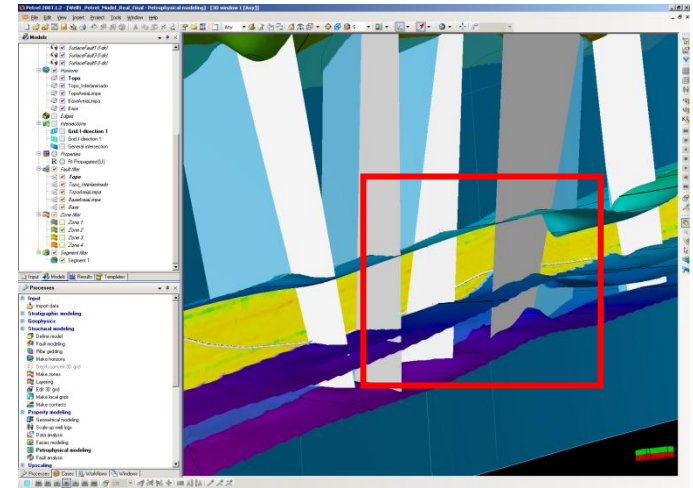
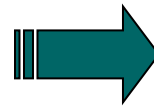
Parameterization  
Modeling & Inversion



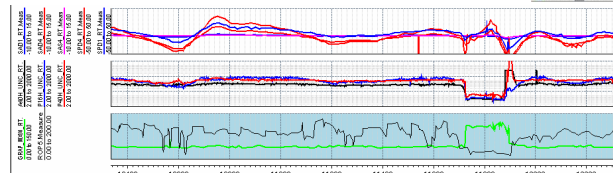
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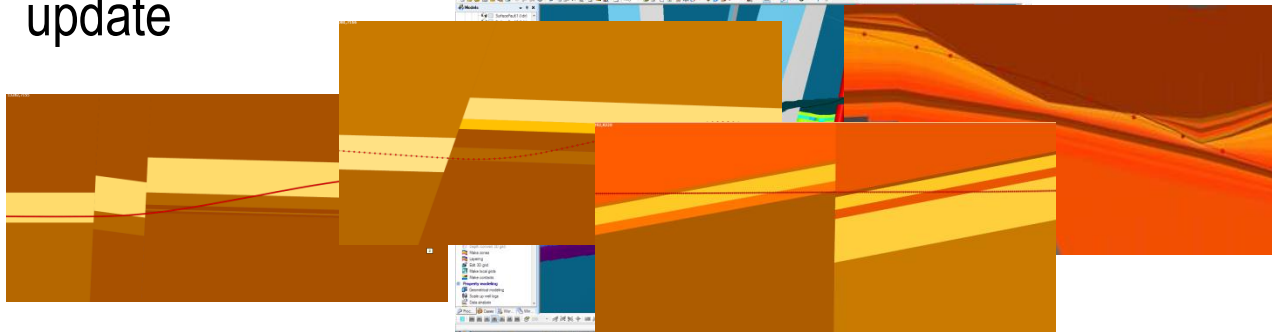
Model  
extraction



Model  
update



Parameterization  
Modeling & Inversion



# HPC Environment for Integrated Multi-tool Modeling

Modeling Library

2.5D, 3D multi-physics

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Modeling Library

2.5D, 3D multi-physics

High-Performance  
Computing Infrastructure

# HPC Environment for Integrated Multi-tool Modeling

Modeling Library

2.5D, 3D multi-physics

High-Performance  
Computing Infrastructure

Service-Oriented Log  
Simulation



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2.5D, 3D multi-physics

High-Performance  
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Service-Oriented Log  
Simulation

Reservoir Modeling and  
Visualization

# HPC Environment for Integrated Multi-tool Modeling

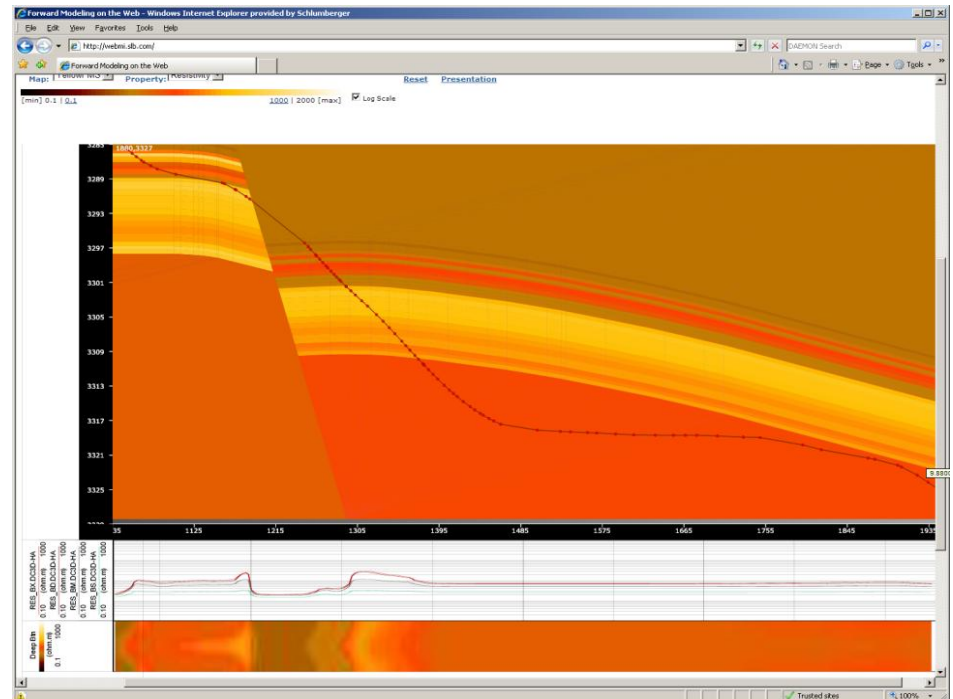
Modeling Library

2.5D, 3D multi-physics

High-Performance  
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Service-Oriented Log  
Simulation

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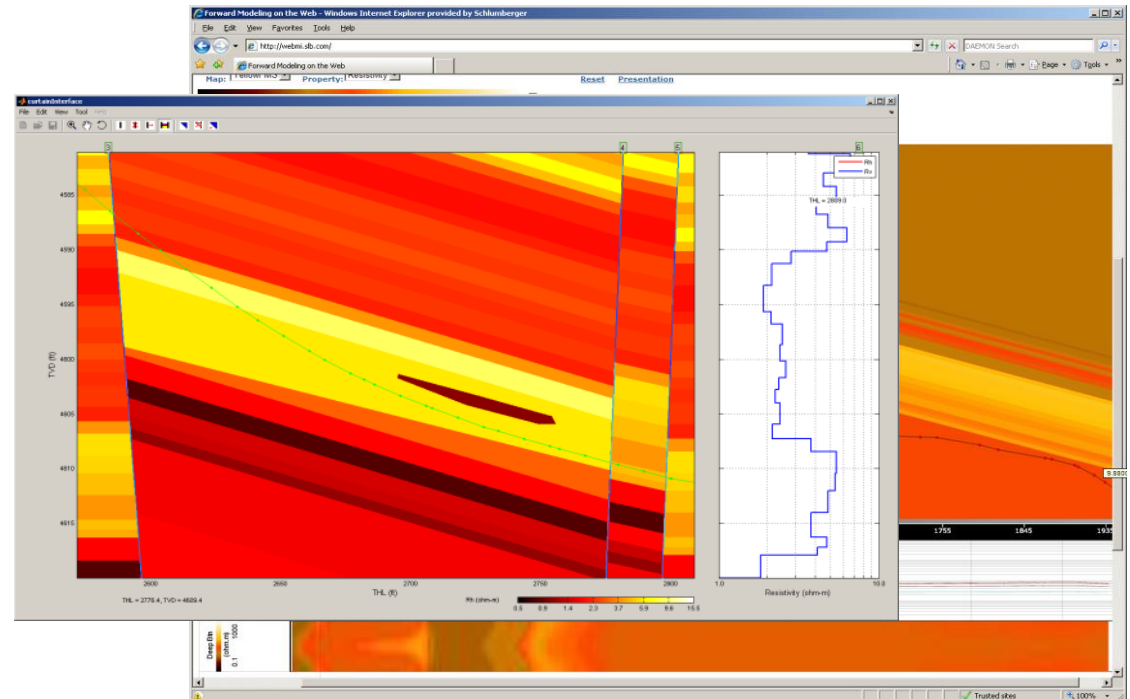
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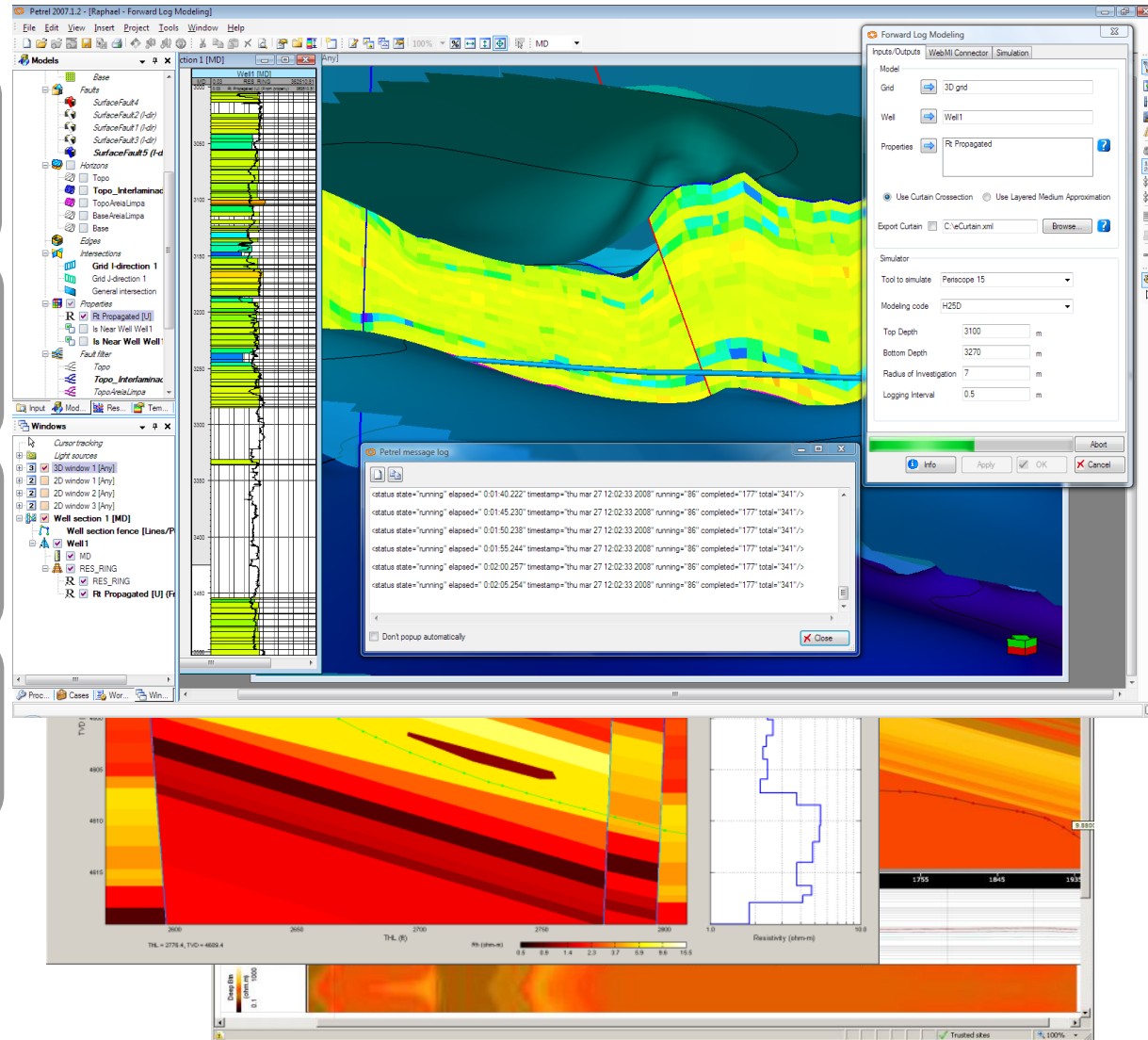
Modeling Library

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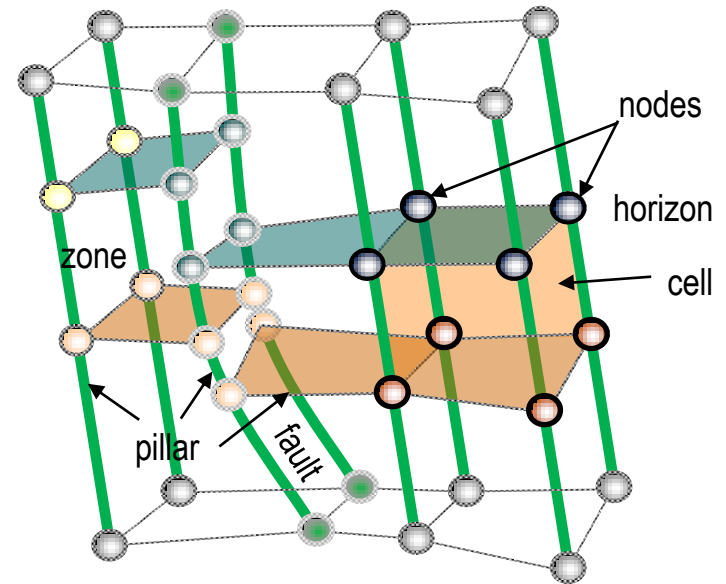
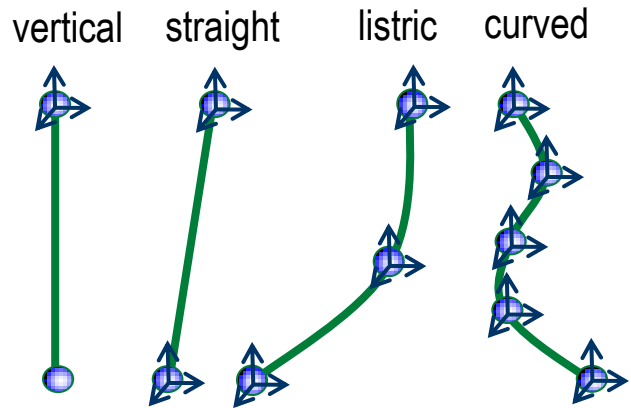
High-Performance Computing Infrastructure

Service-Oriented Log Simulation

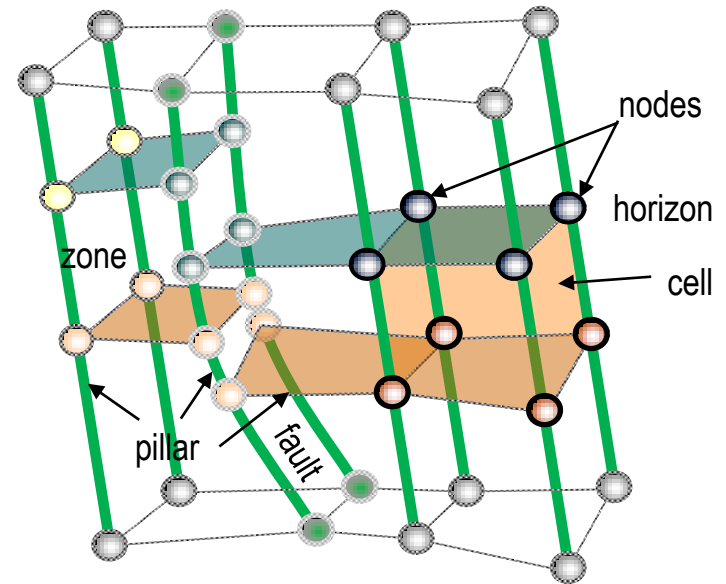
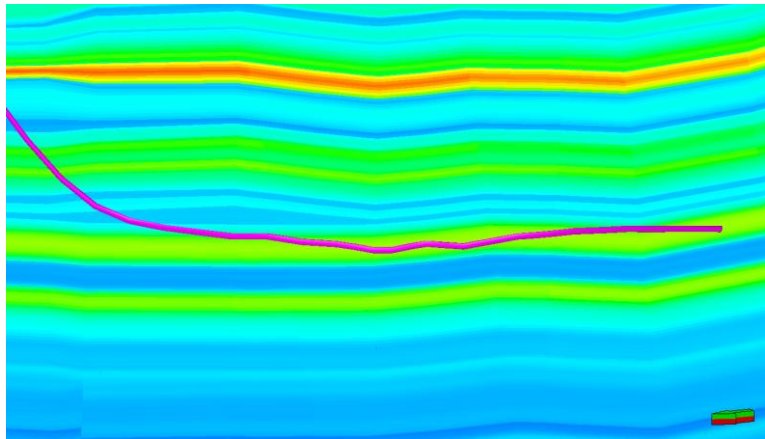
Reservoir Modeling and Visualization



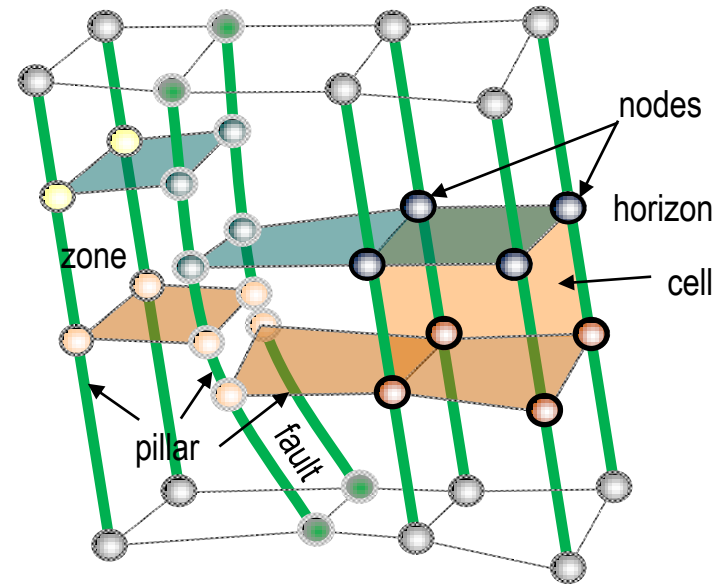
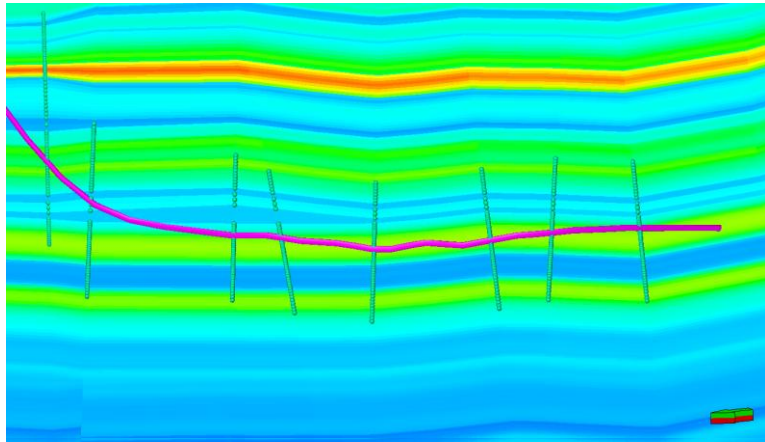
# Well Log Interpretation Curtain Section Models Compatible with 3D Pillar Grids Geomodels



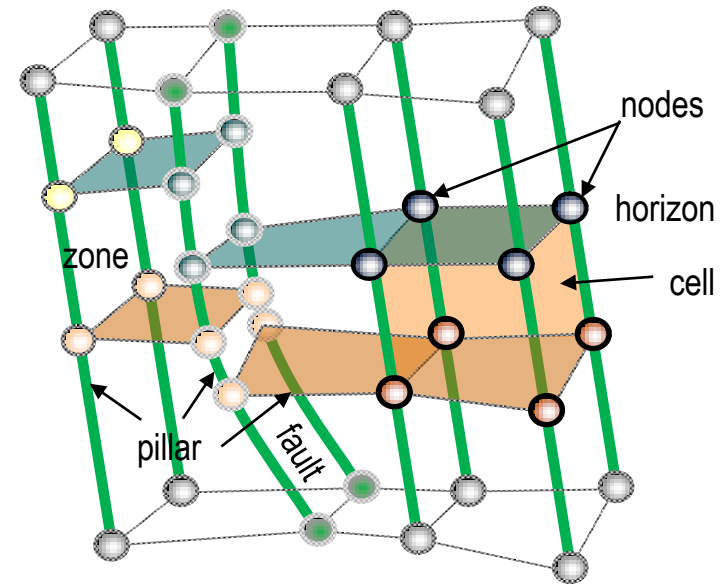
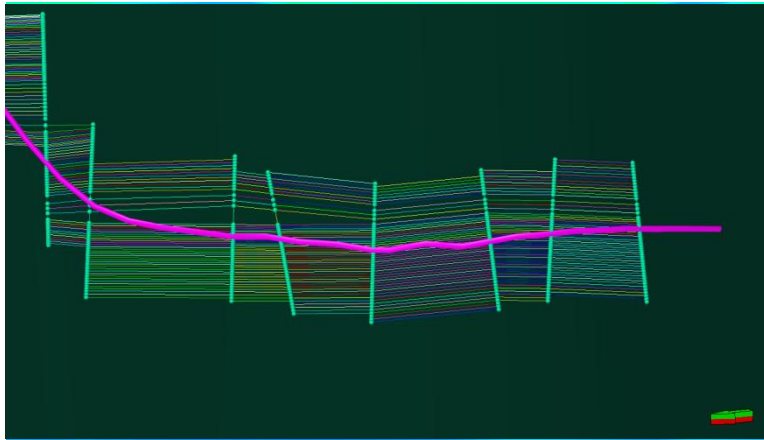
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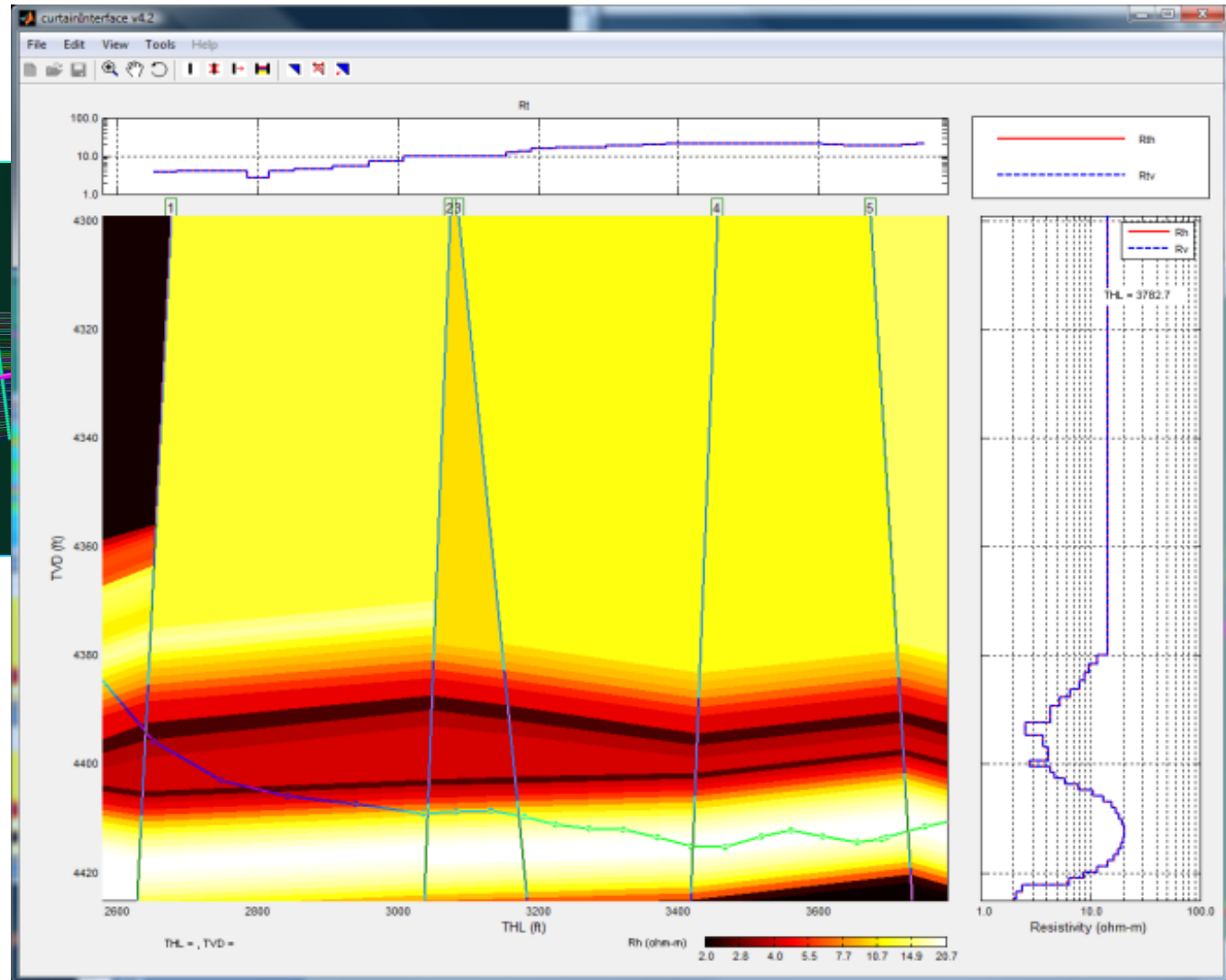
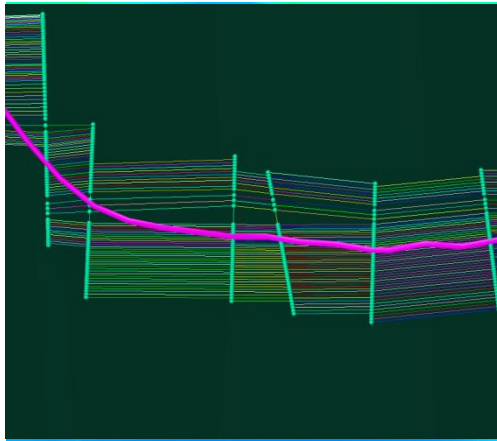


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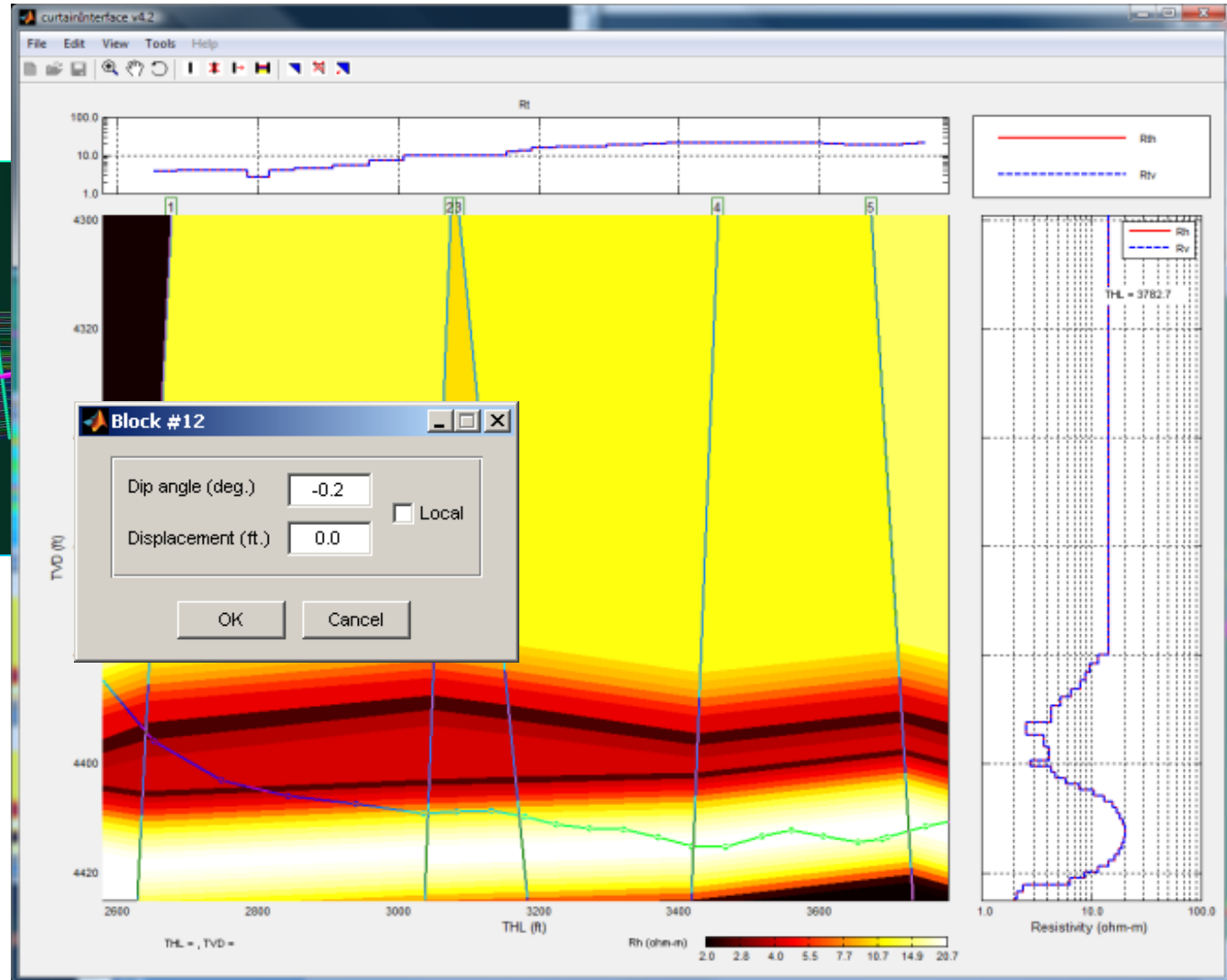
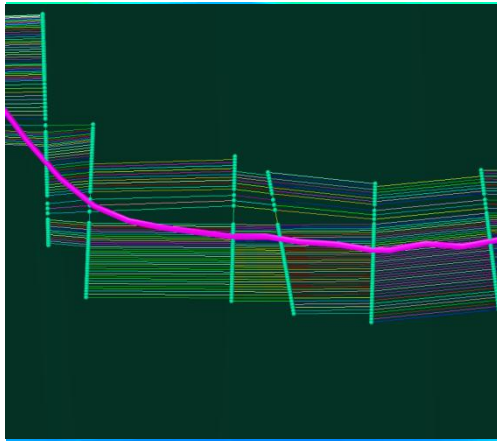




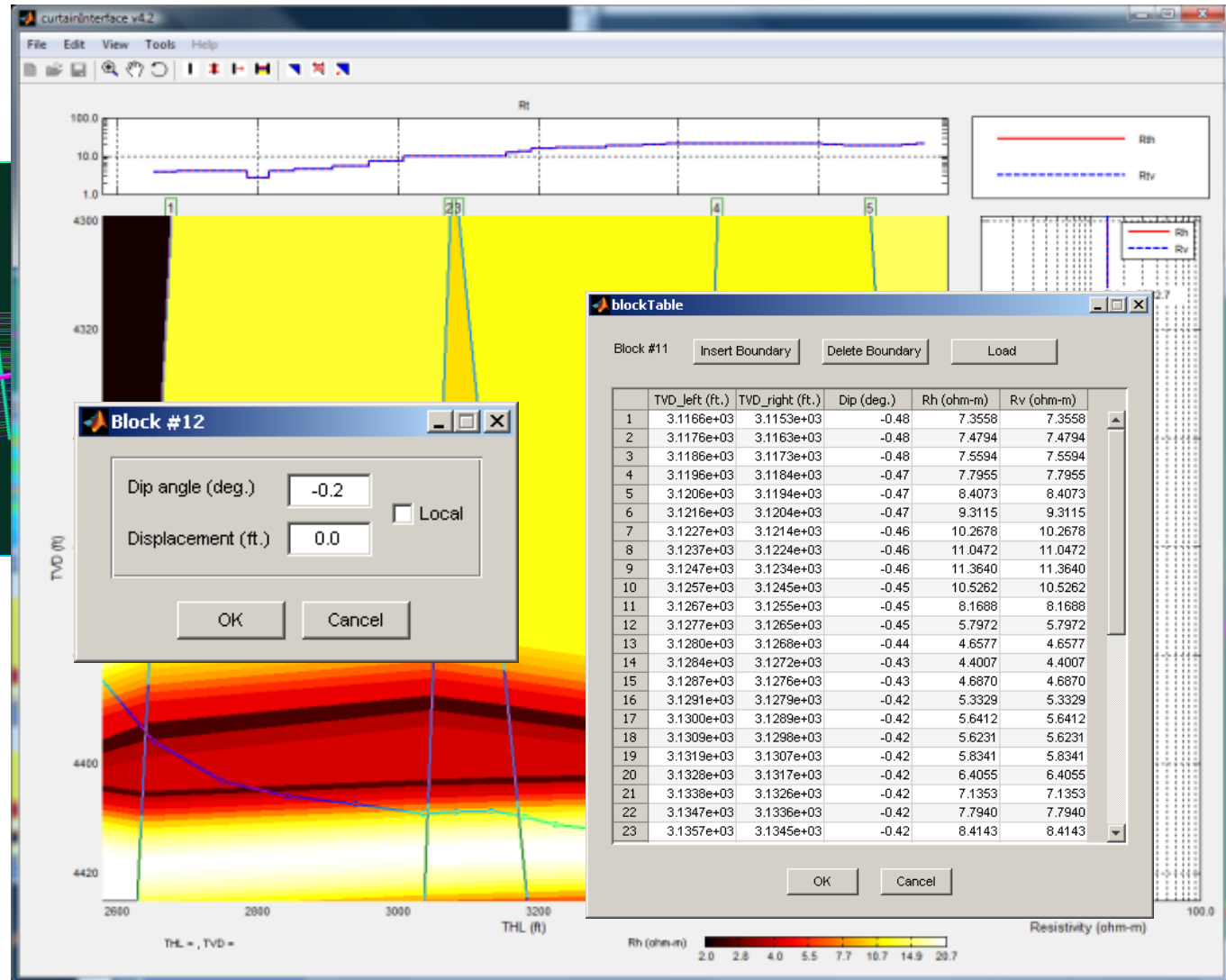
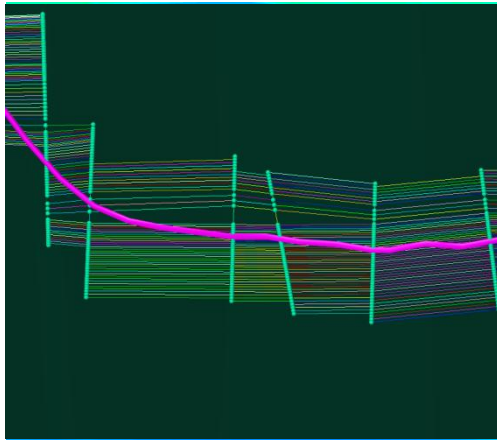
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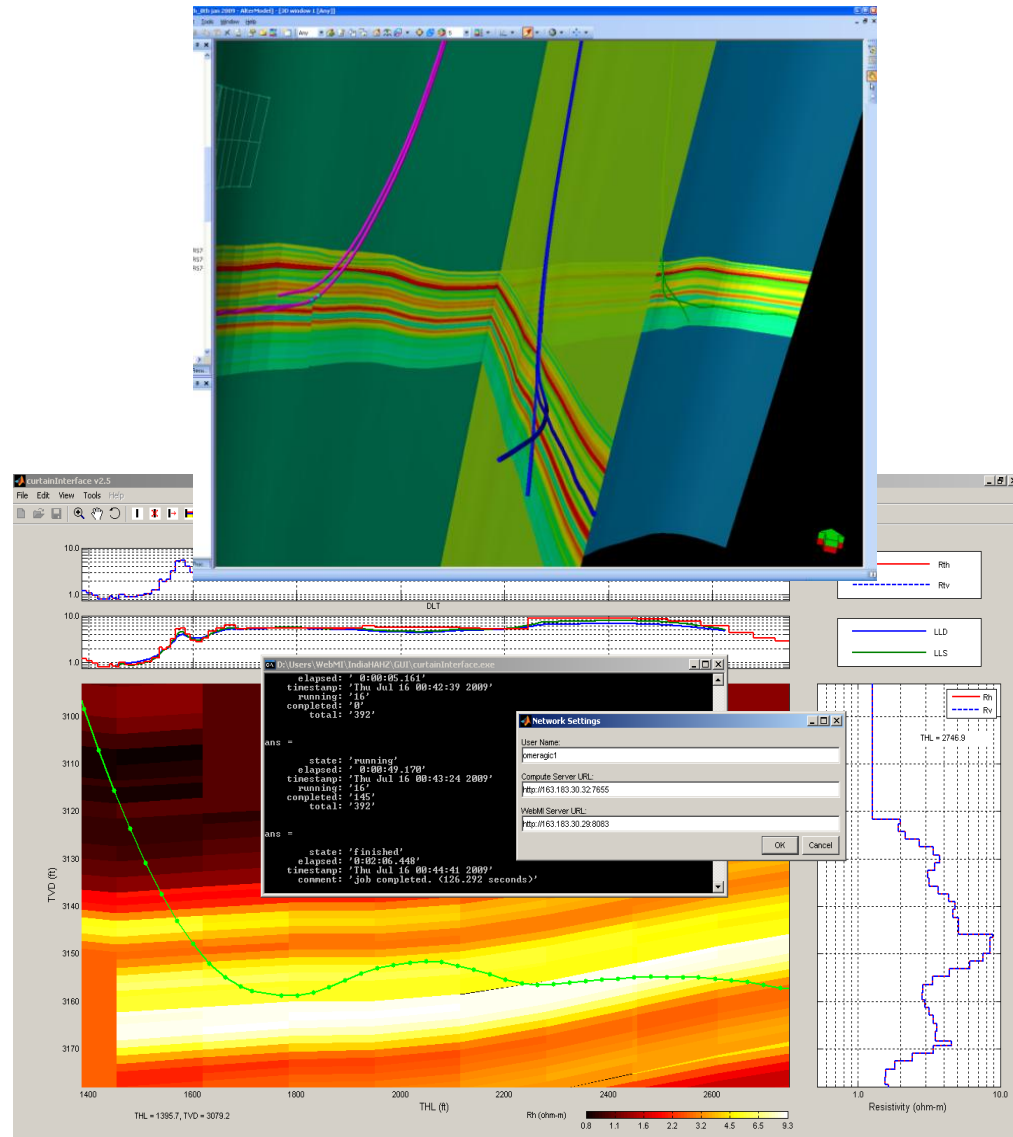
# Customized HPC Modeling Environment Used in Supergiant Carbonate Field Study

Increase the recovery factor –  
Seismic-to-simulation study

Interpret 100s of HA/HZ wells  
(WL and LWD data)

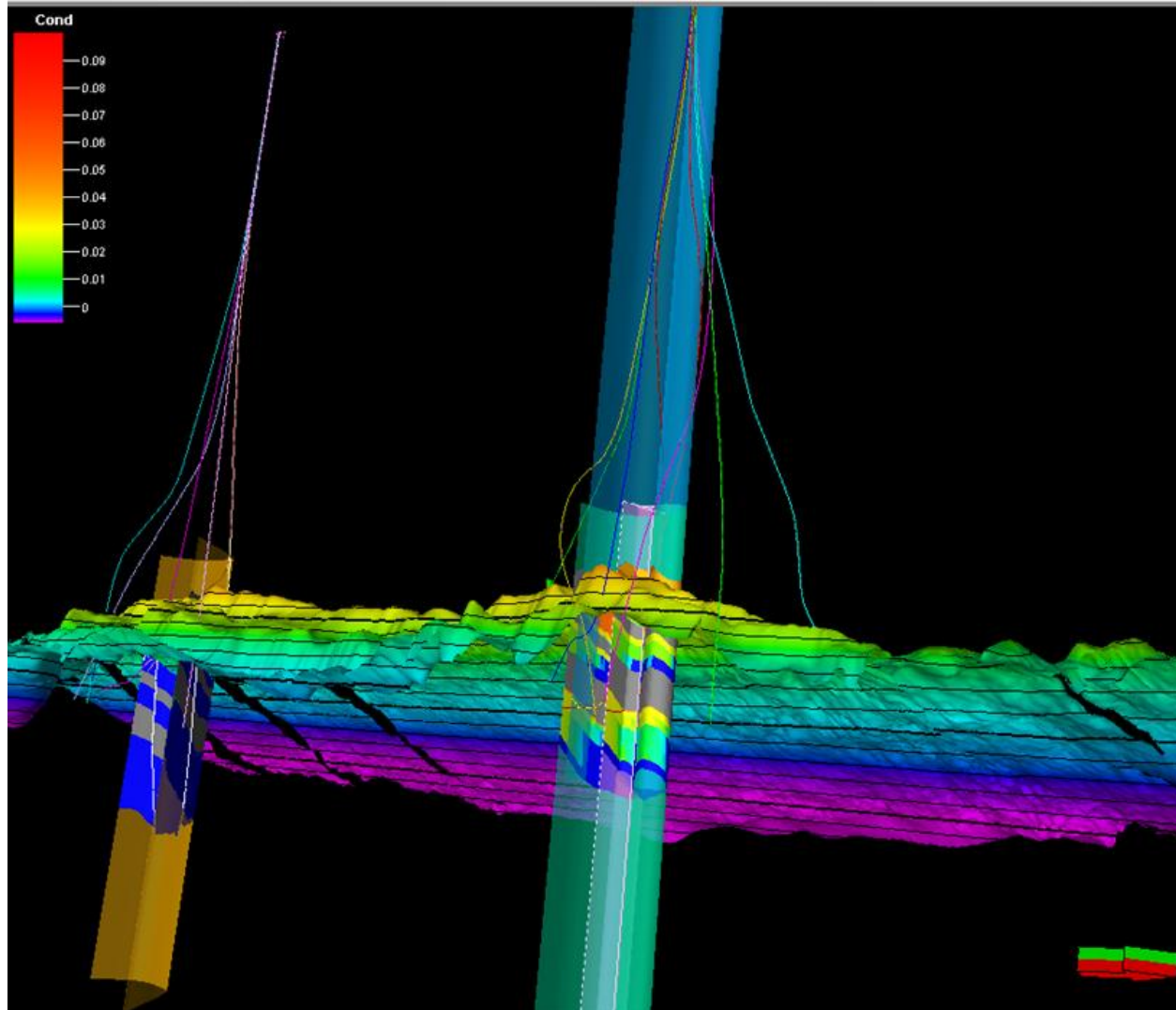
- Saturation modeling of that scale has not been attempted before
- Reduce  $R_t$  modeling uncertainty

Process three wells/day on 28  
cores (compared to one well per  
three days)



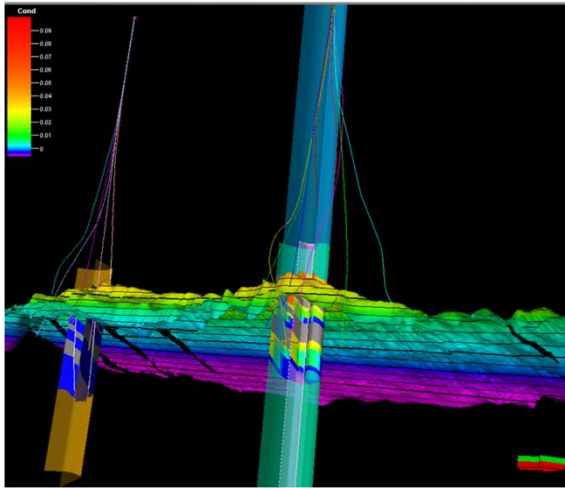
# FFR Workflow

All components installed in the client's office



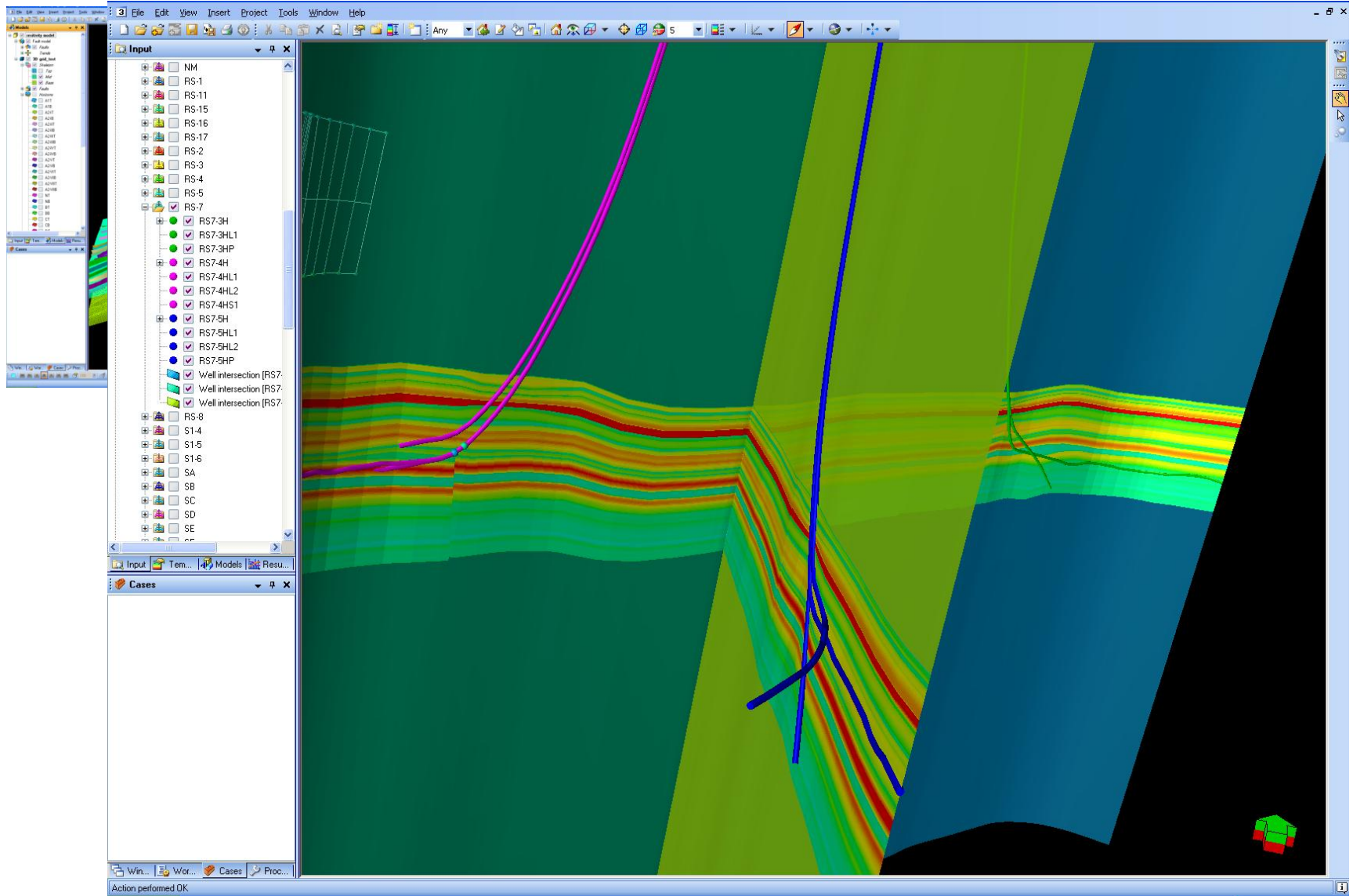
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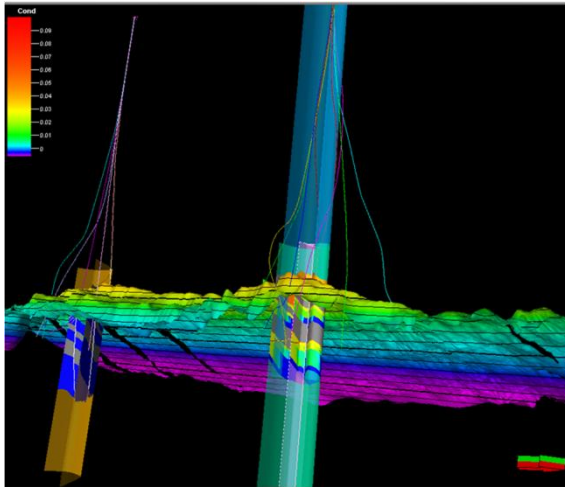
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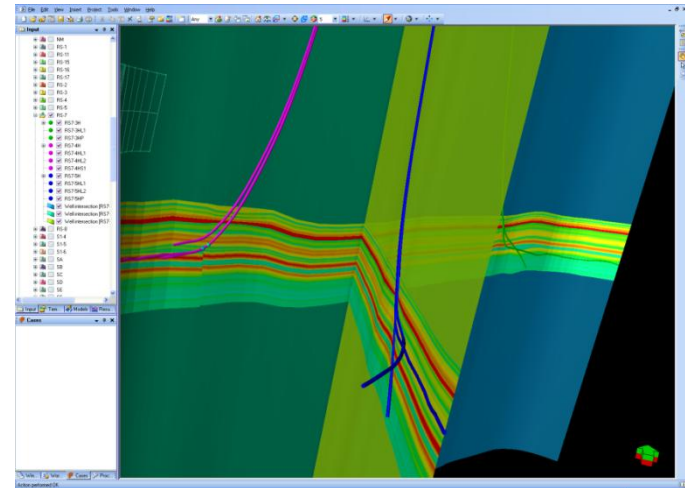
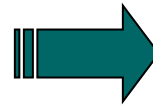


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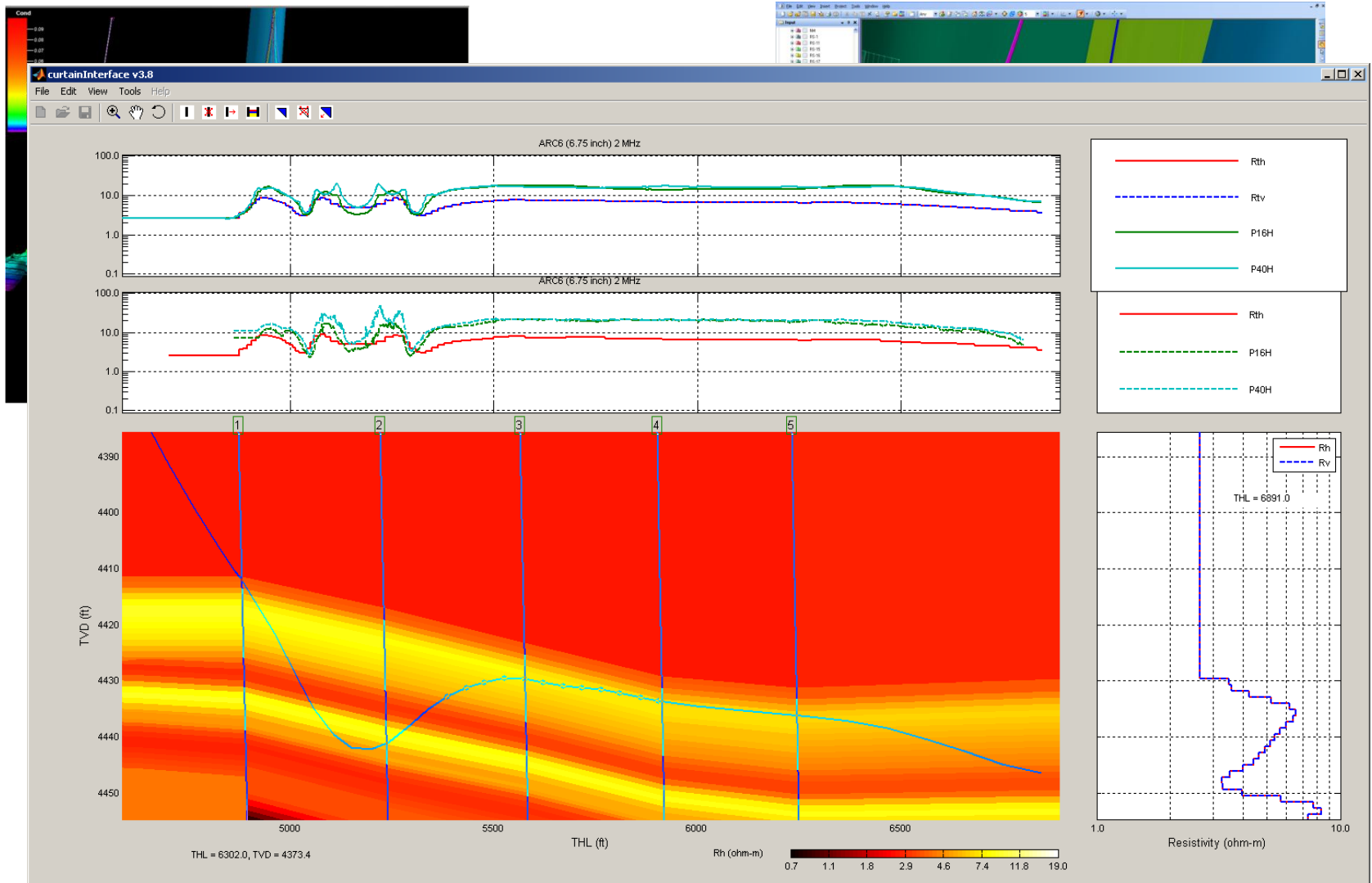
Model  
extraction





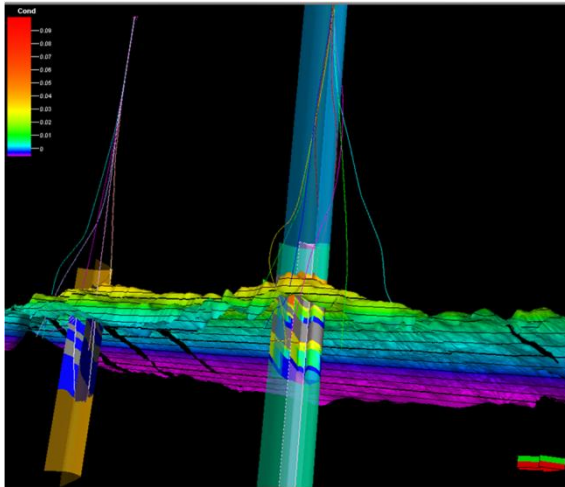
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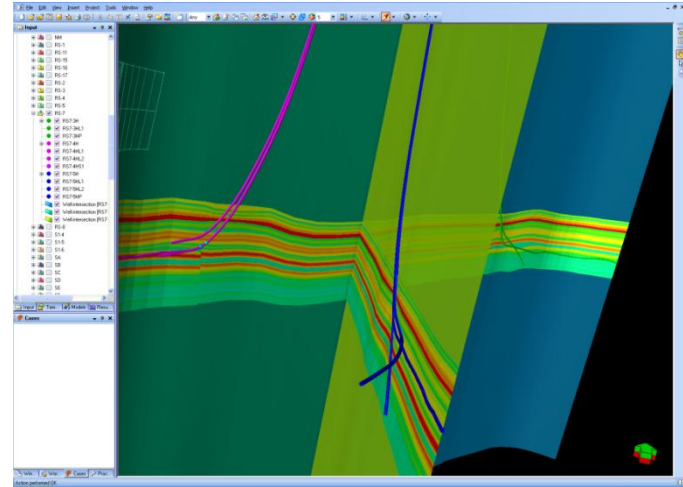
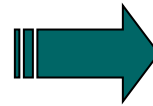


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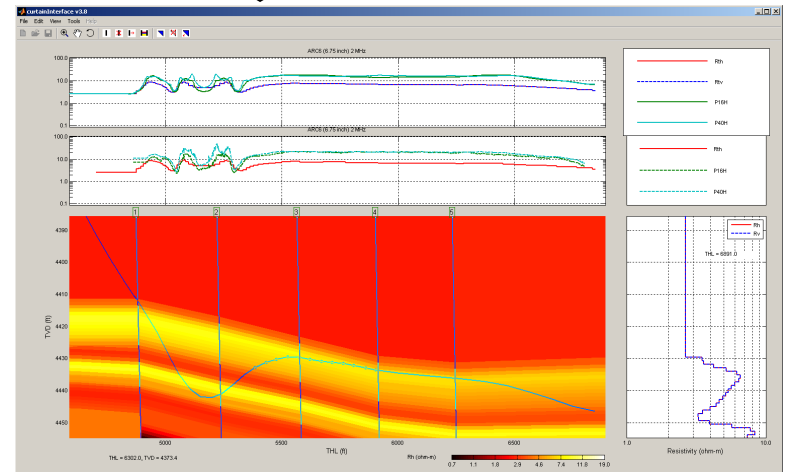
All components installed in the client's office



Model  
extraction

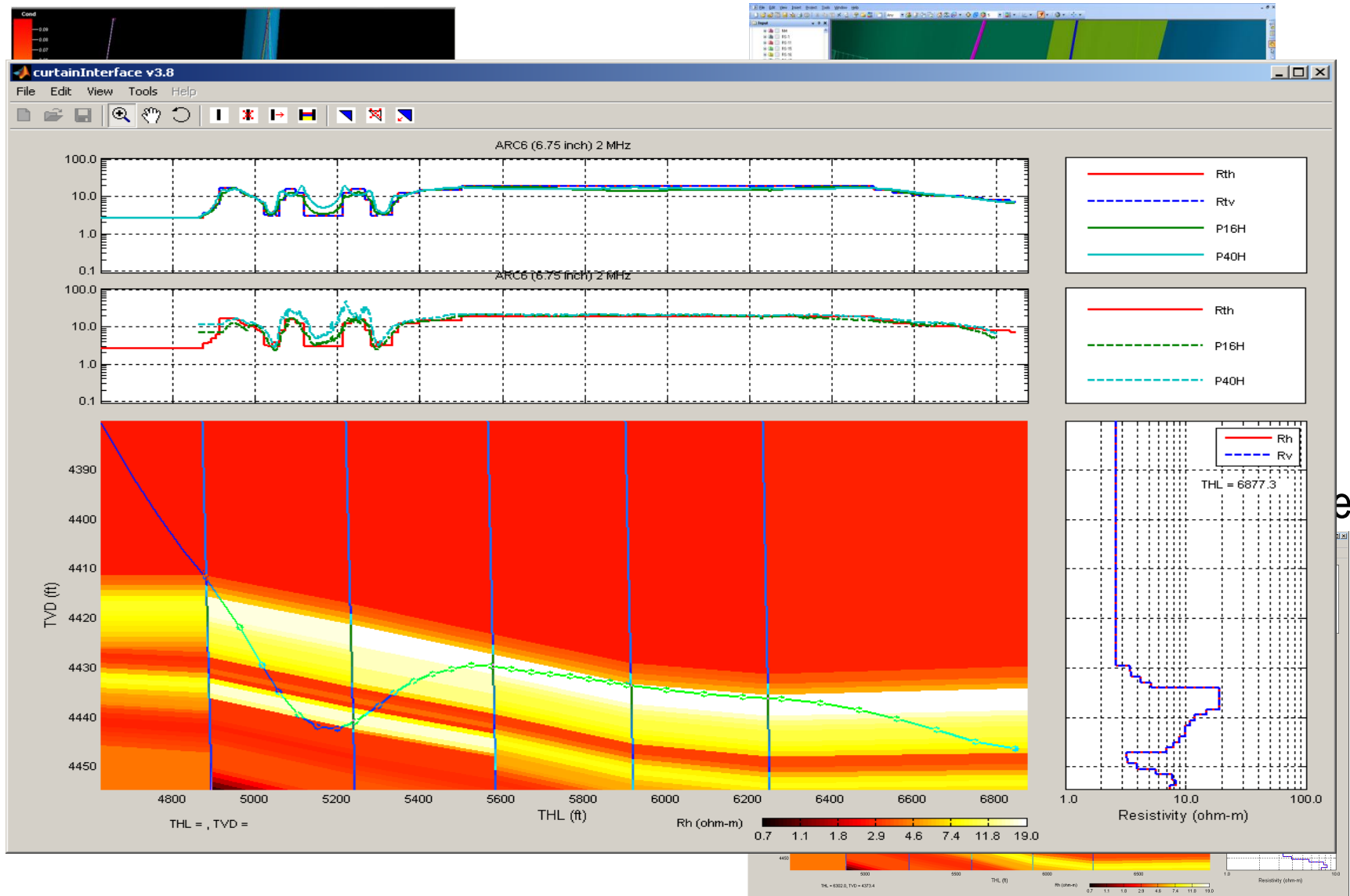


Export  
Parameterized Model



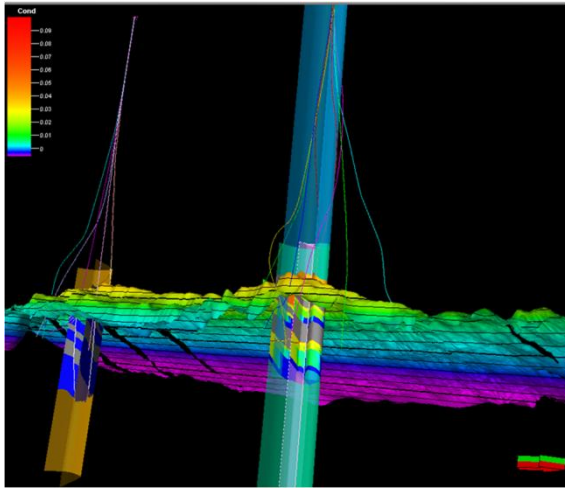
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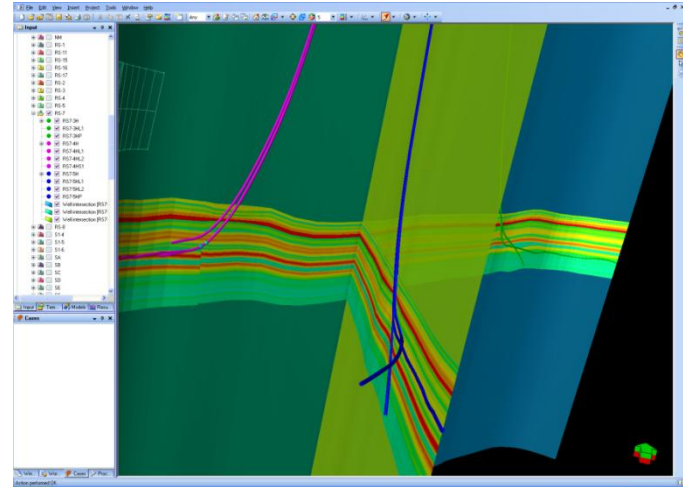
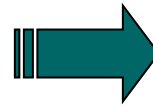


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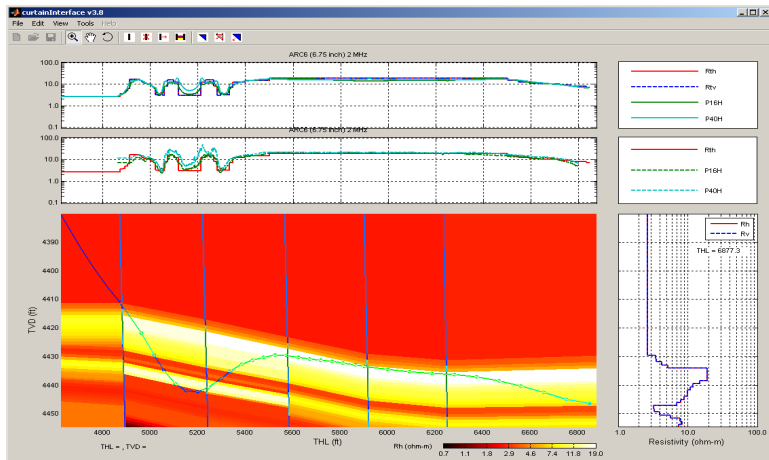
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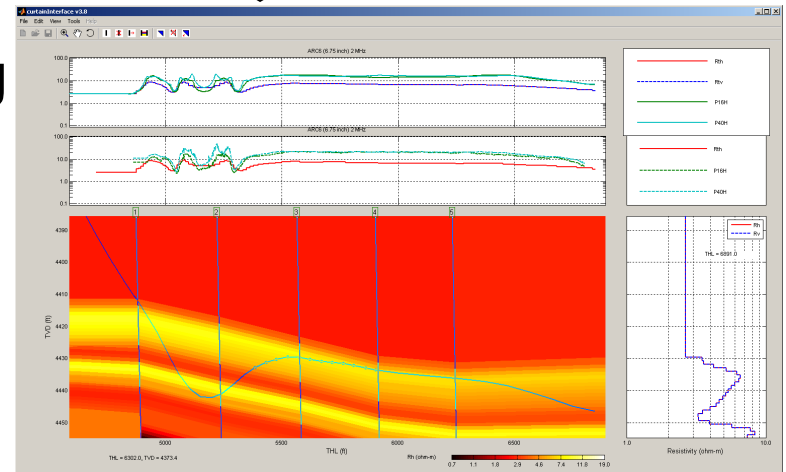
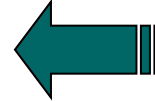
Model  
extraction



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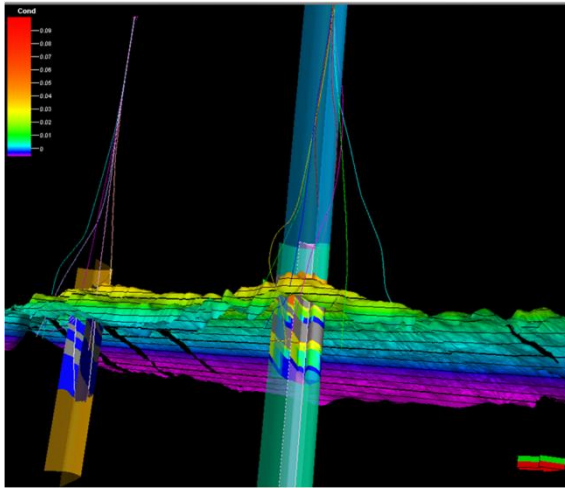


Modeling  
Editing

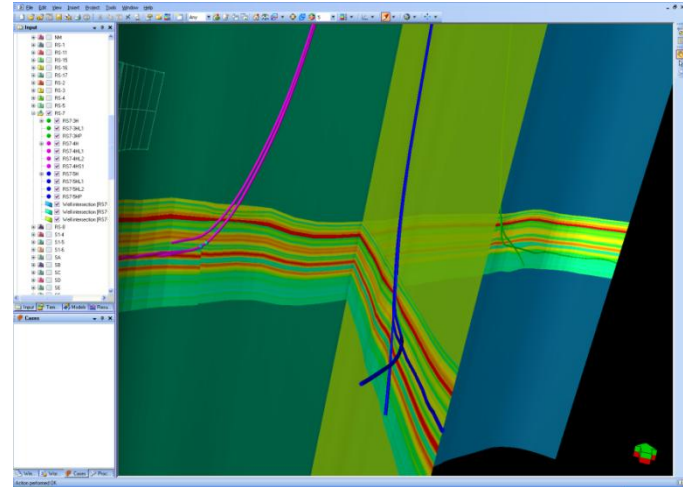
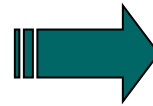


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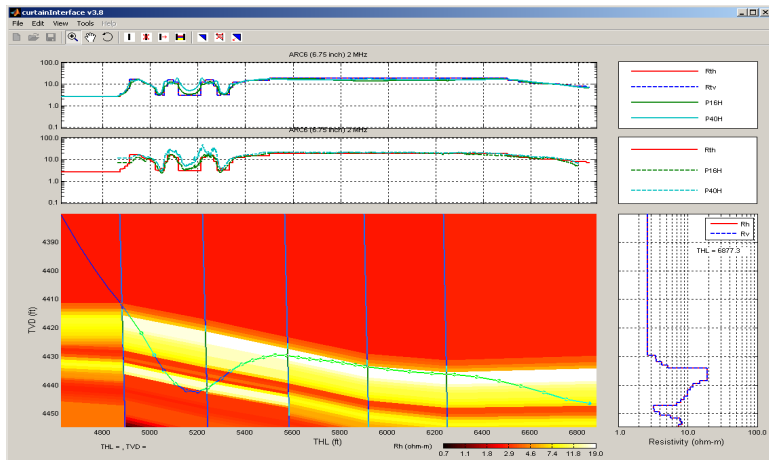
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Model extraction



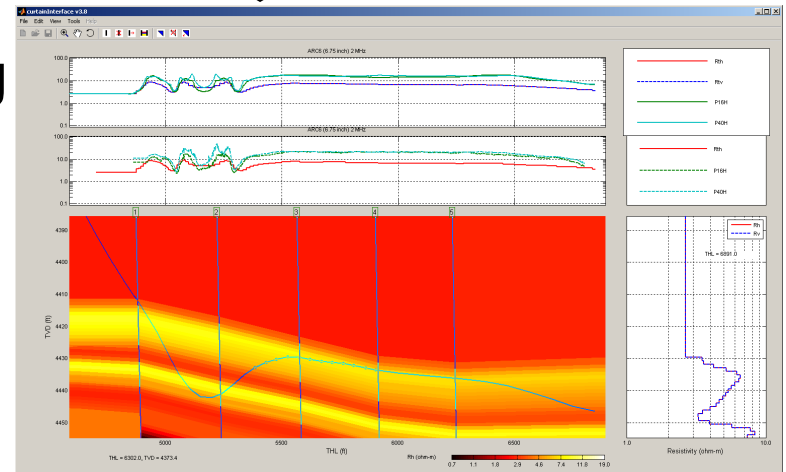
Model Update  
(manual)



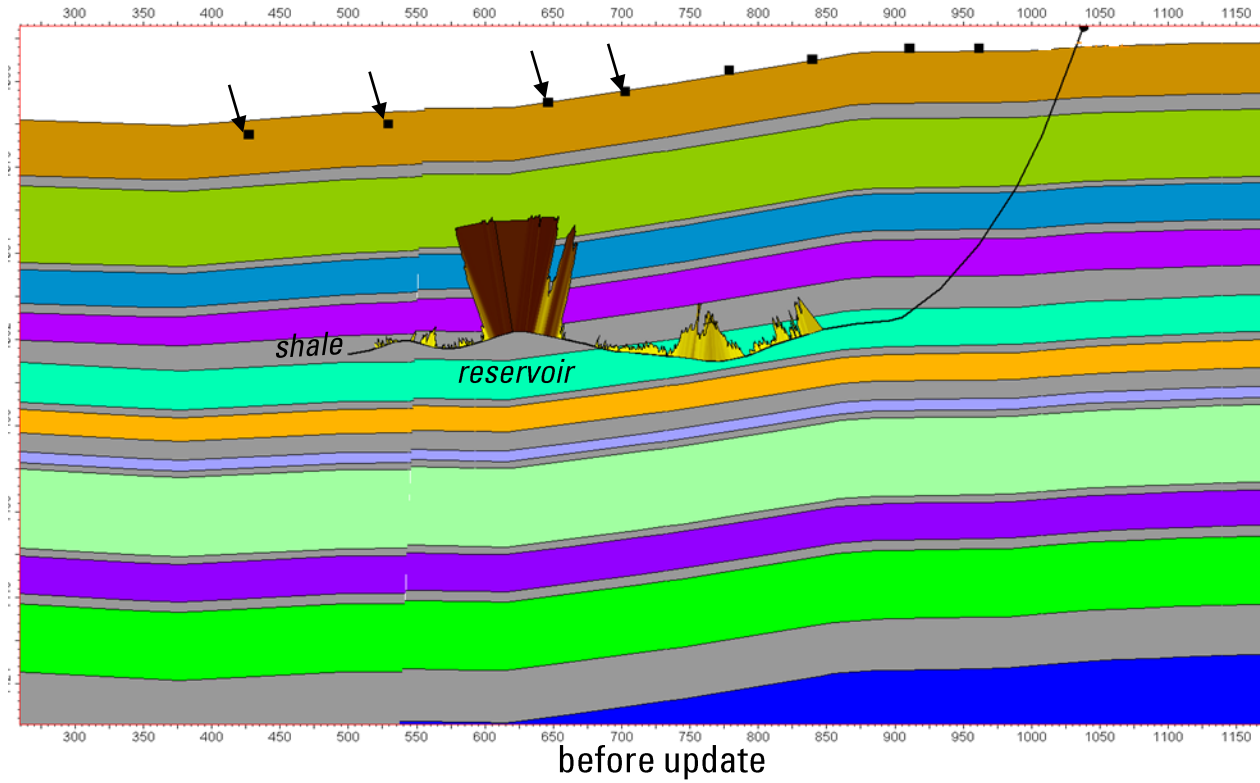
Modeling  
Editing



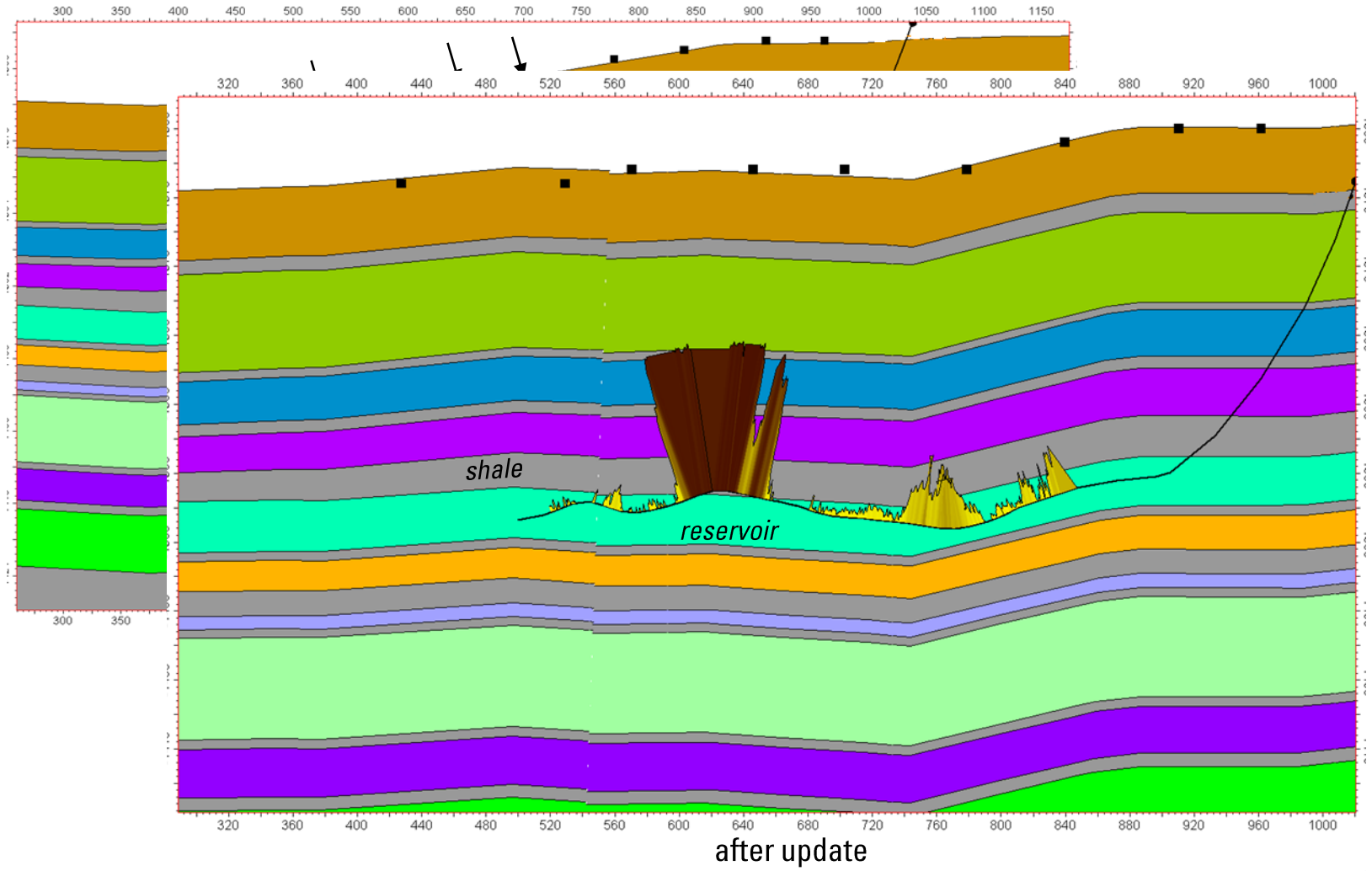
Export  
Parameterized Model



# Manual Model Update



# Manual Model Update



# 3D Automated Model Update

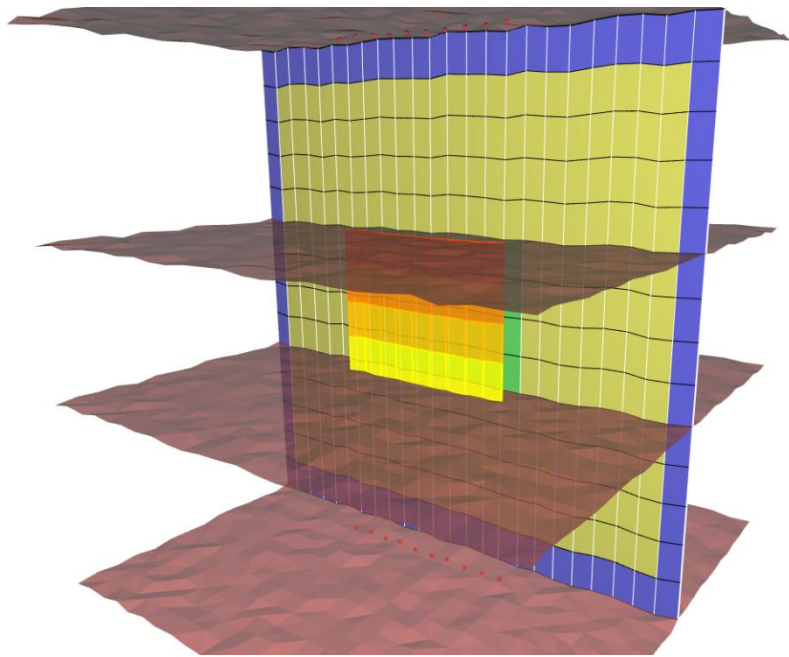
- Assume that topology and number of cells is not changed
- Modify section blended into the reservoir background model



# 3D Automated Model Update

- Assume that topology and number of cells is not changed
- Modify section blended into the reservoir background model

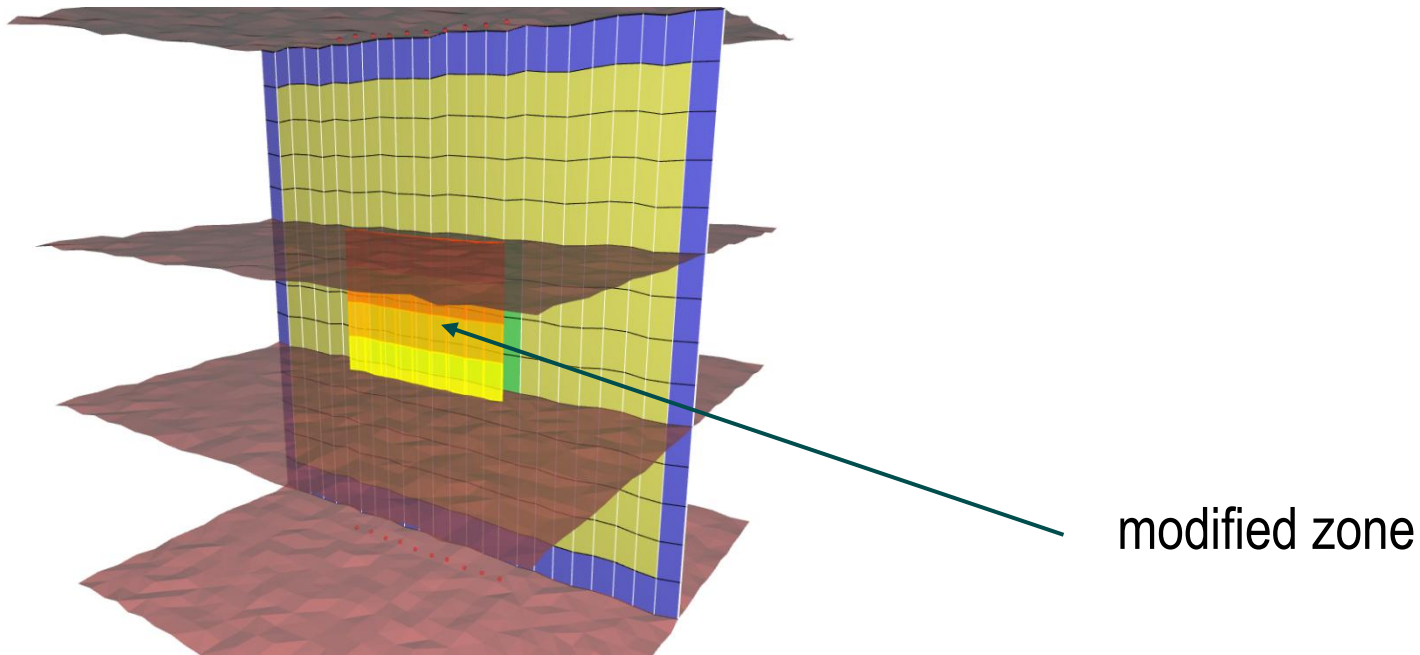
original model



# 3D Automated Model Update

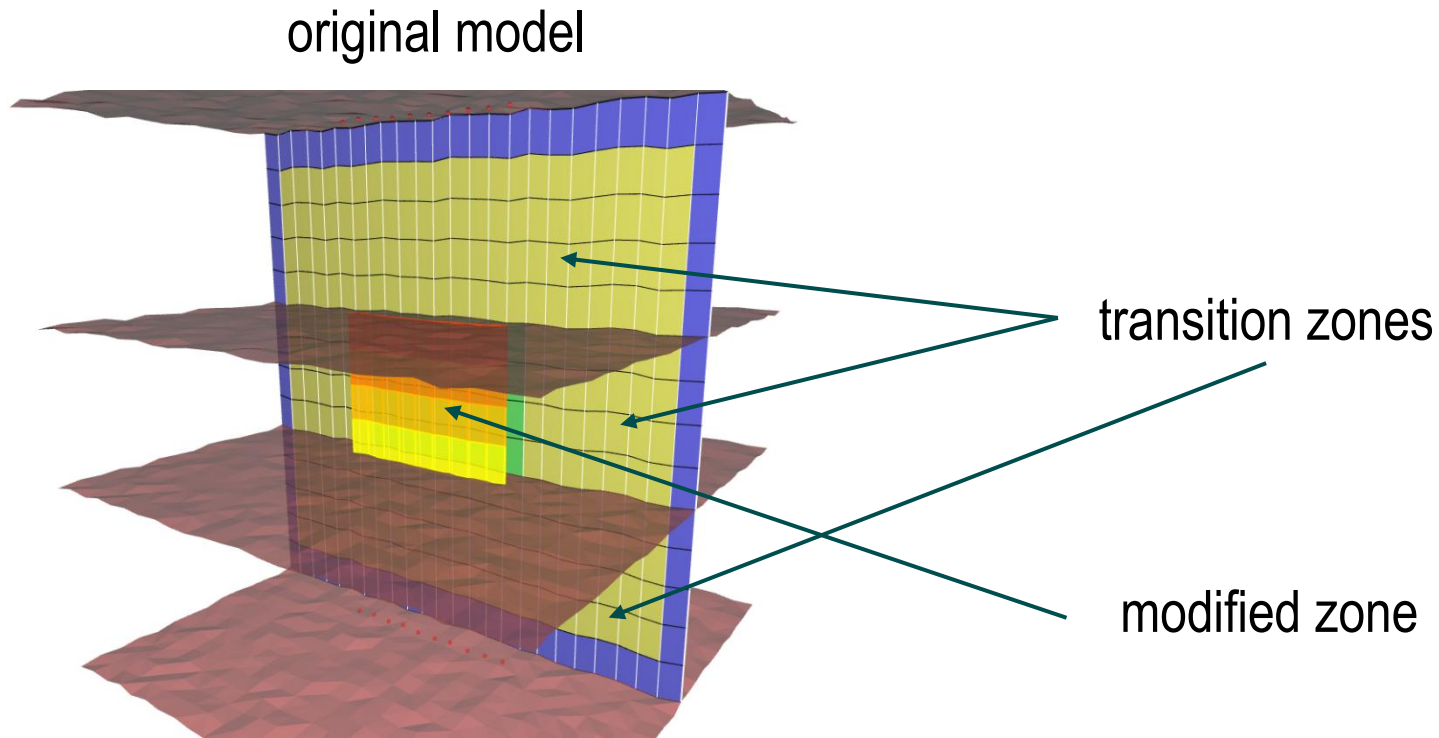
- Assume that topology and number of cells is not changed
- Modify section blended into the reservoir background model

original model



# 3D Automated Model Update

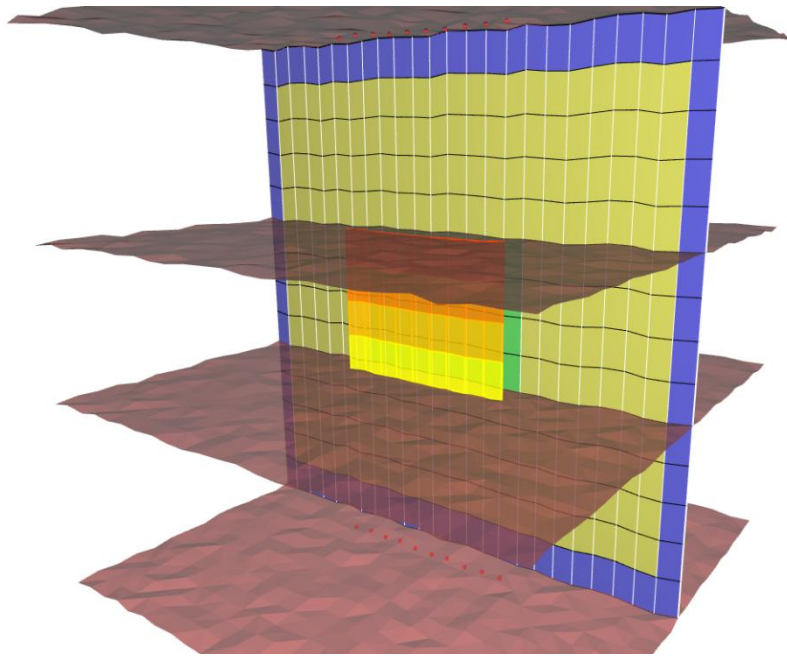
- Assume that topology and number of cells is not changed
- Modify section blended into the reservoir background model



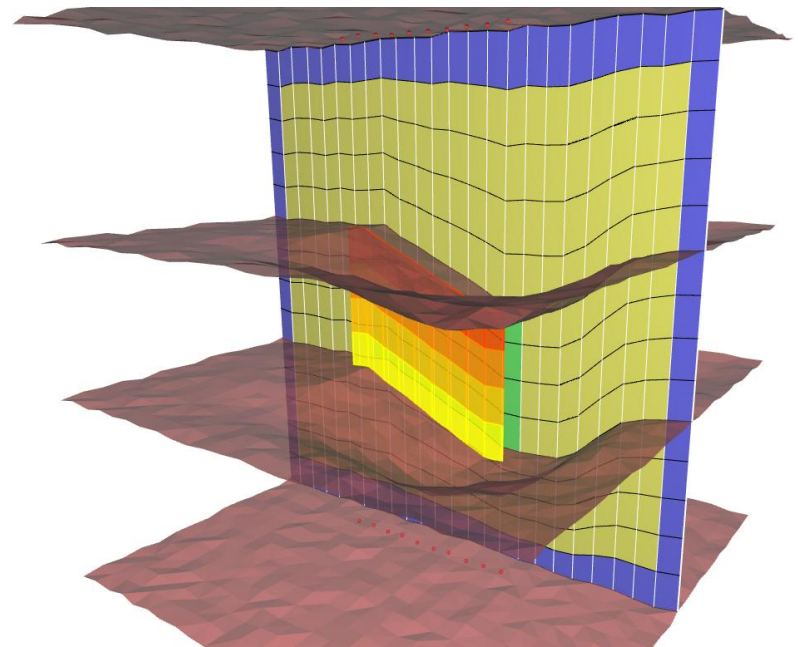
# 3D Automated Model Update

- Assume that topology and number of cells is not changed
- Modify section blended into the reservoir background model

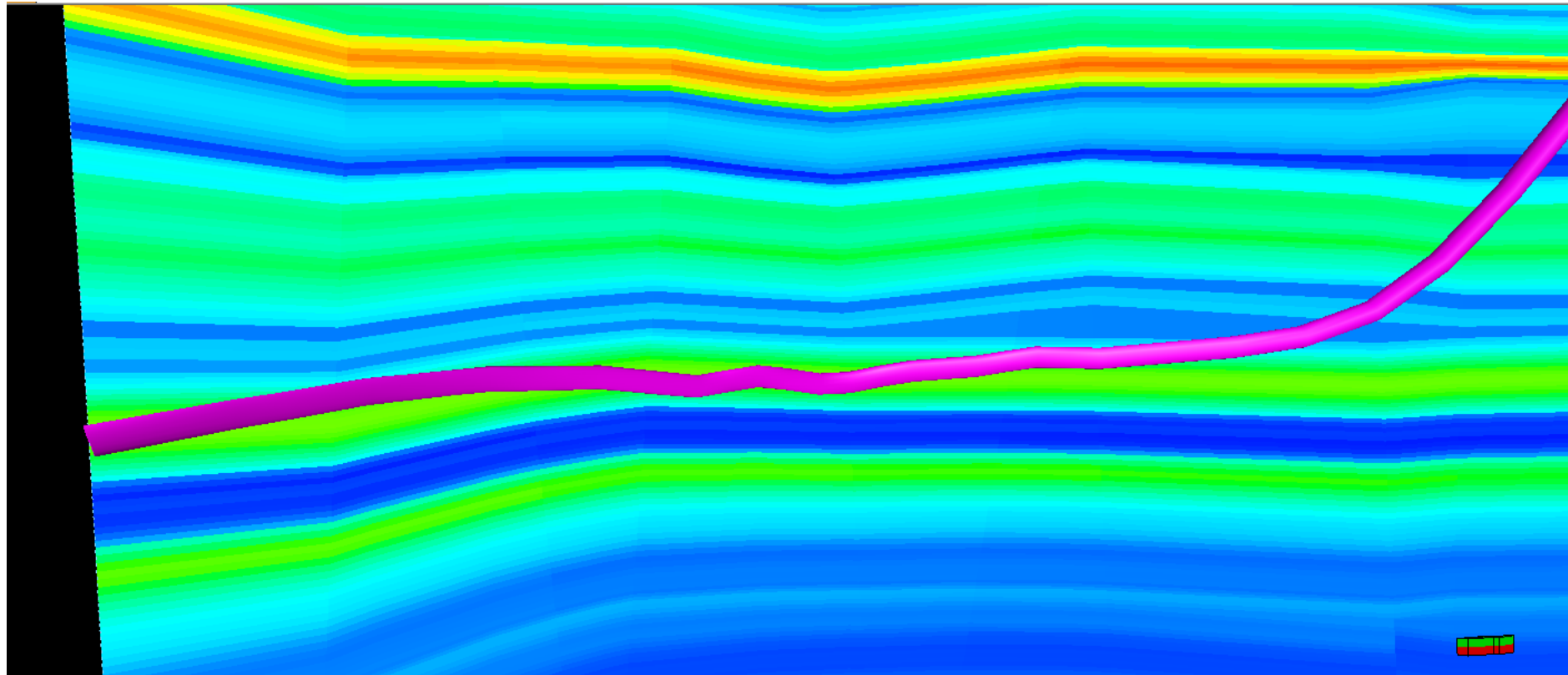
original model



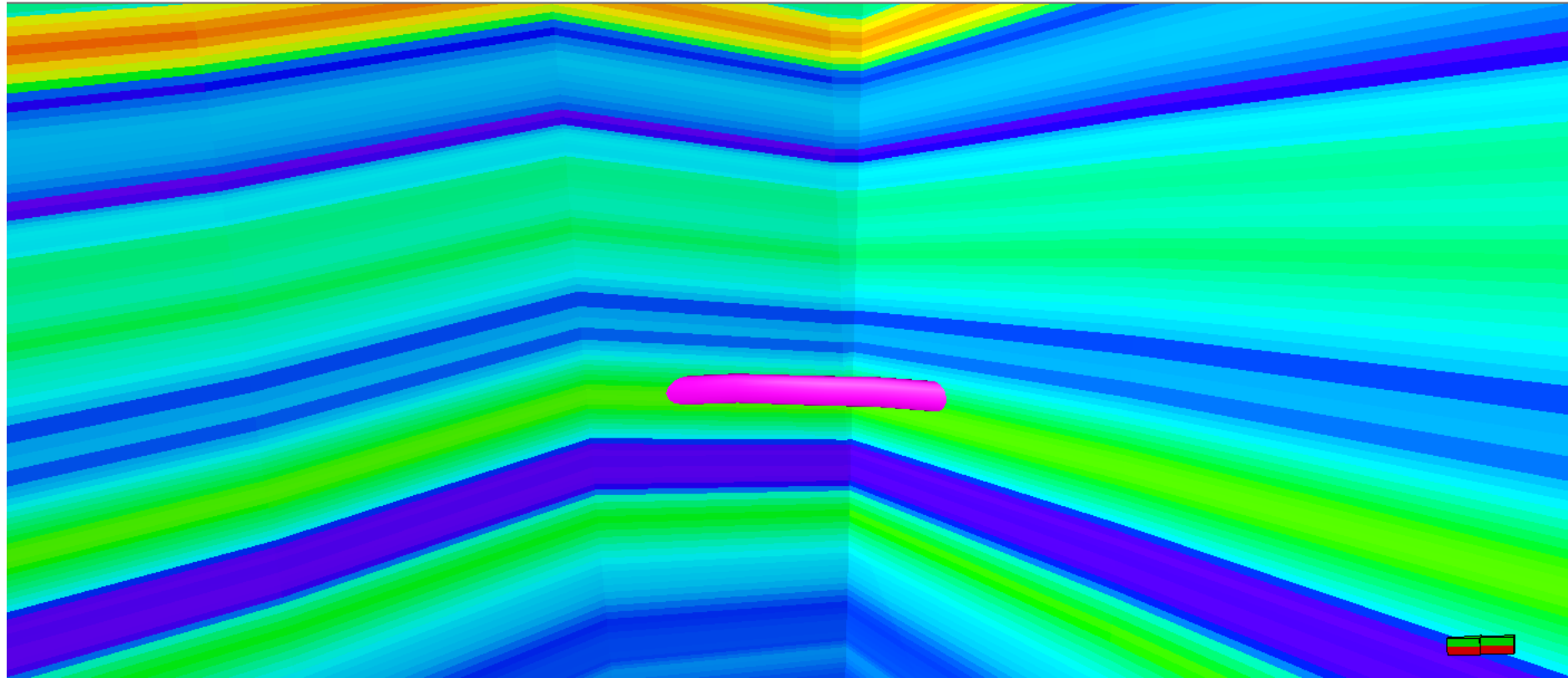
modified model



# Propagation Of Changes In Model Geometry



# Propagation Of Changes In Model Geometry



# Propagation Of Changes In Model Geometry

**Update model**

**1: Provide Input**

Grid:

Well:

**2: Define Curtain**

Start (MD):  m

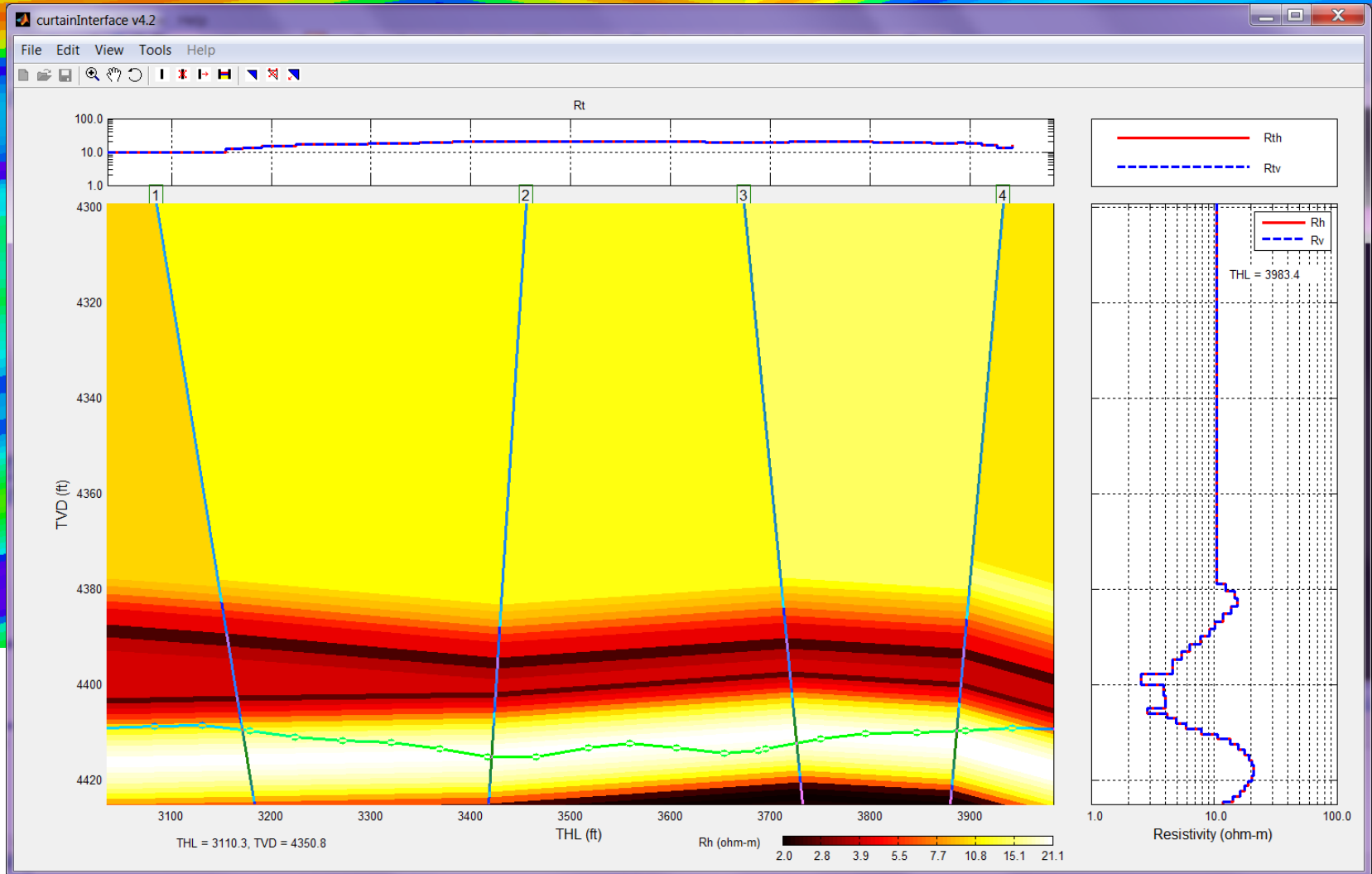
Stop (MD):  m

Extent:  m

**3: Define Model Updating Zones**

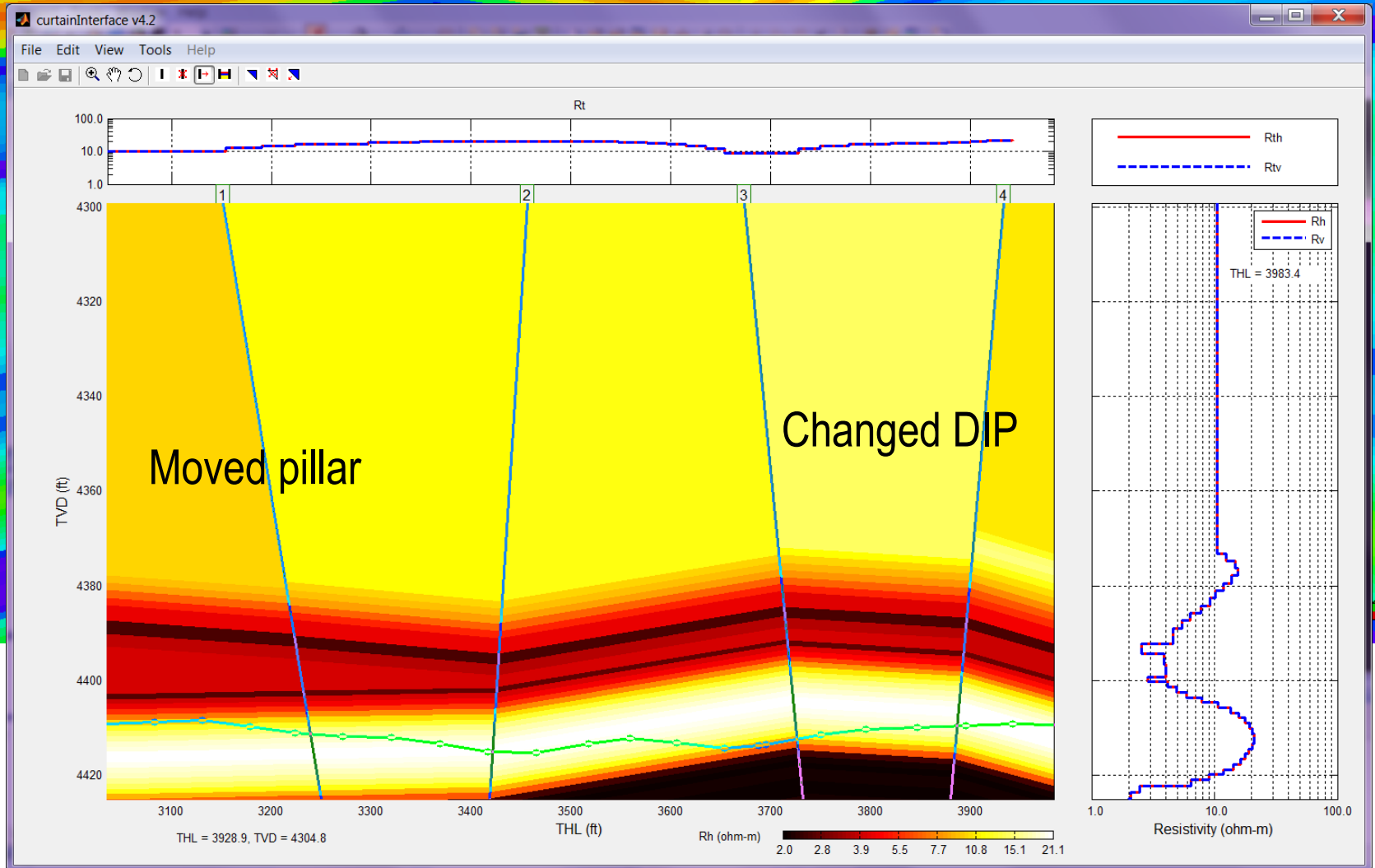
**4: Update Model**

# Propagation Of Changes In Model Geometry

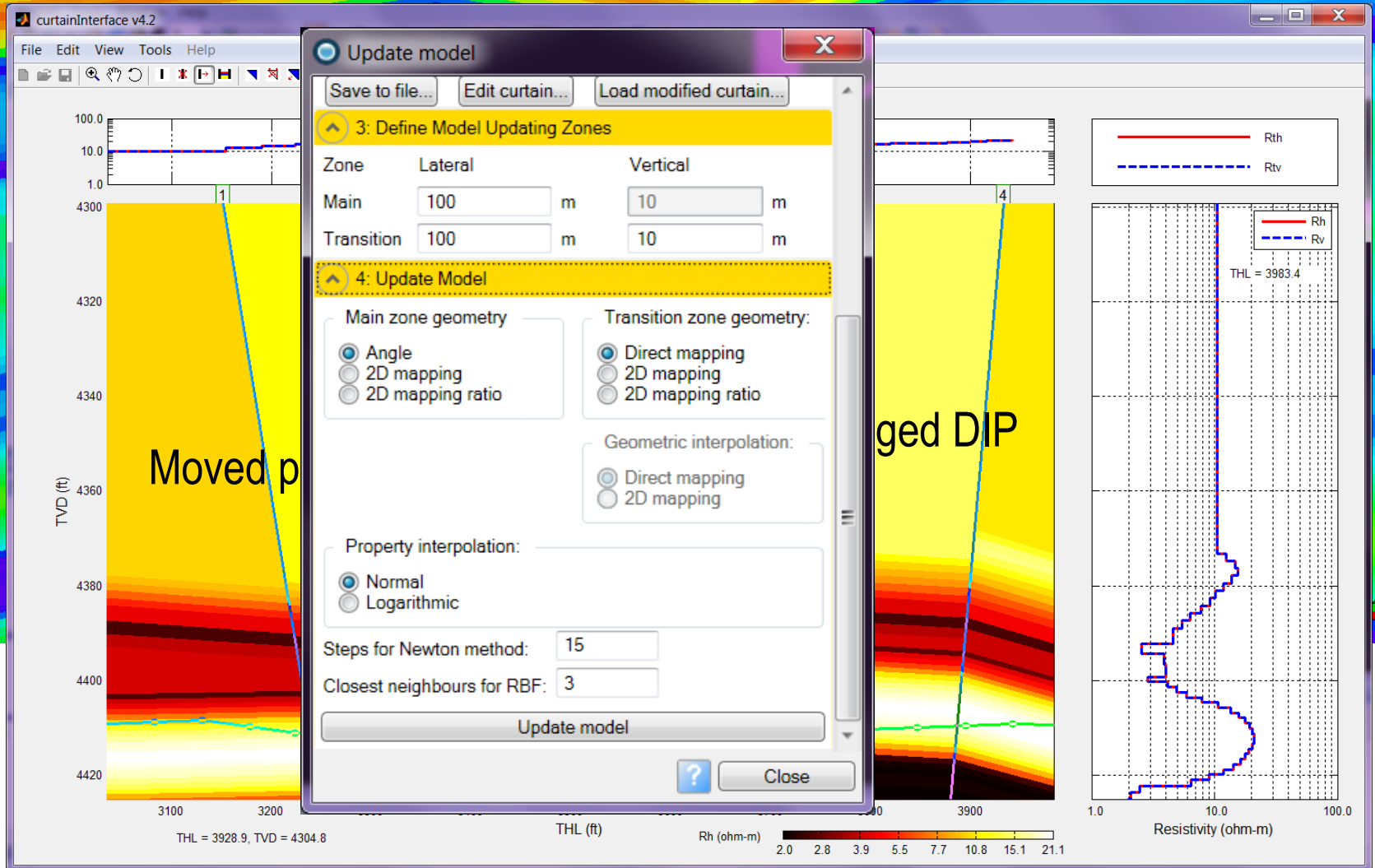




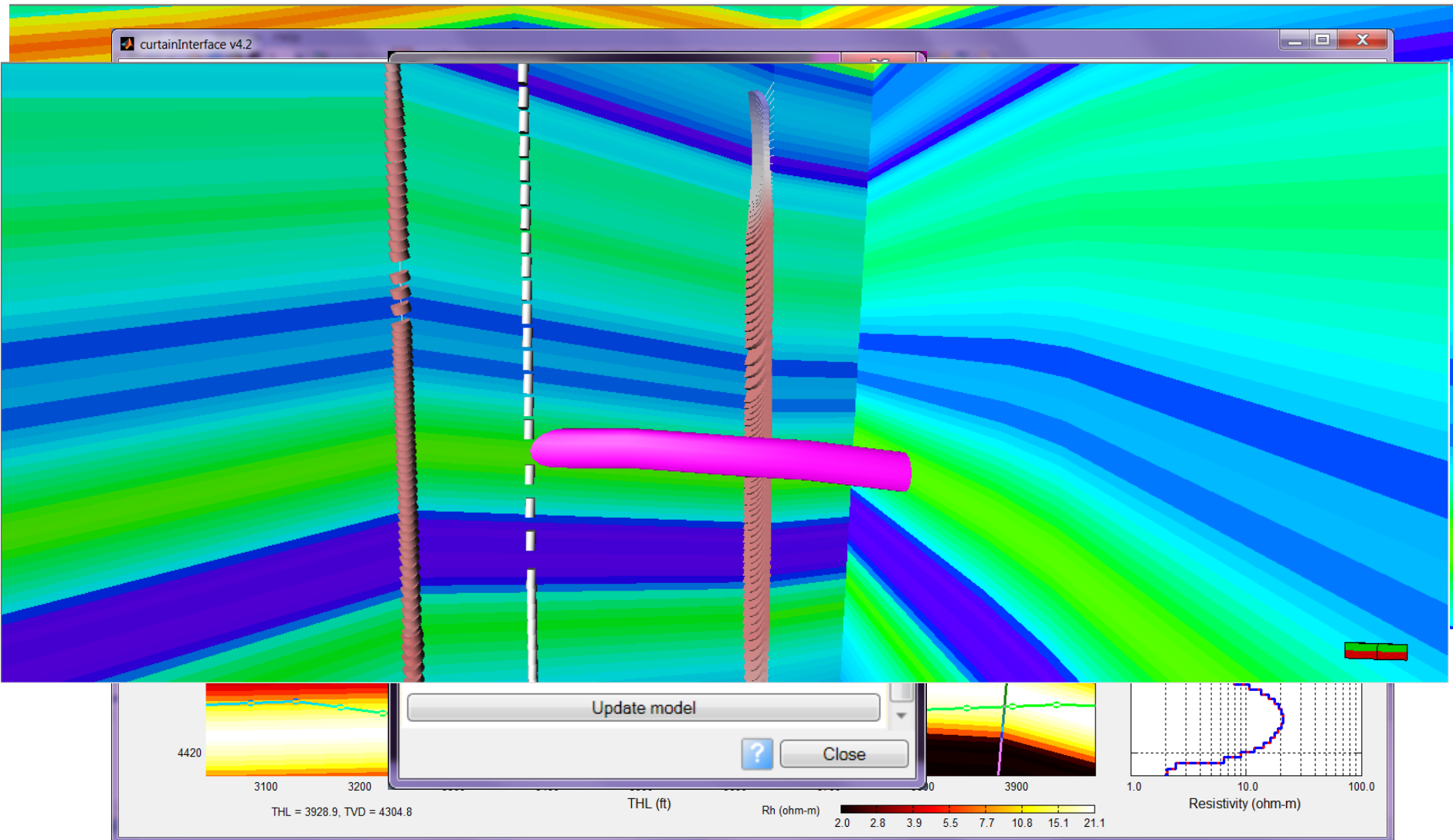
# Propagation Of Changes In Model Geometry



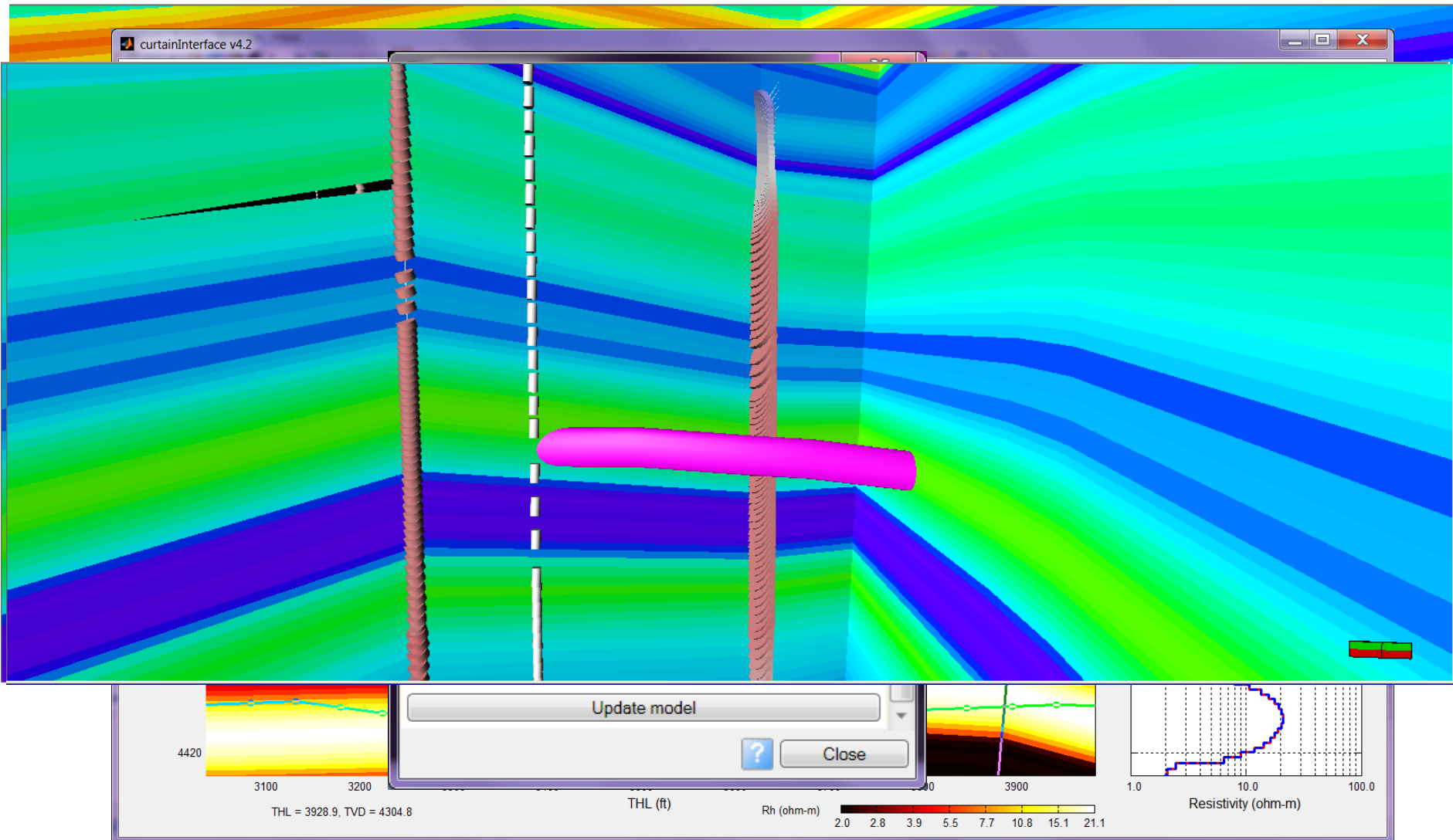
# Propagation Of Changes In Model Geometry



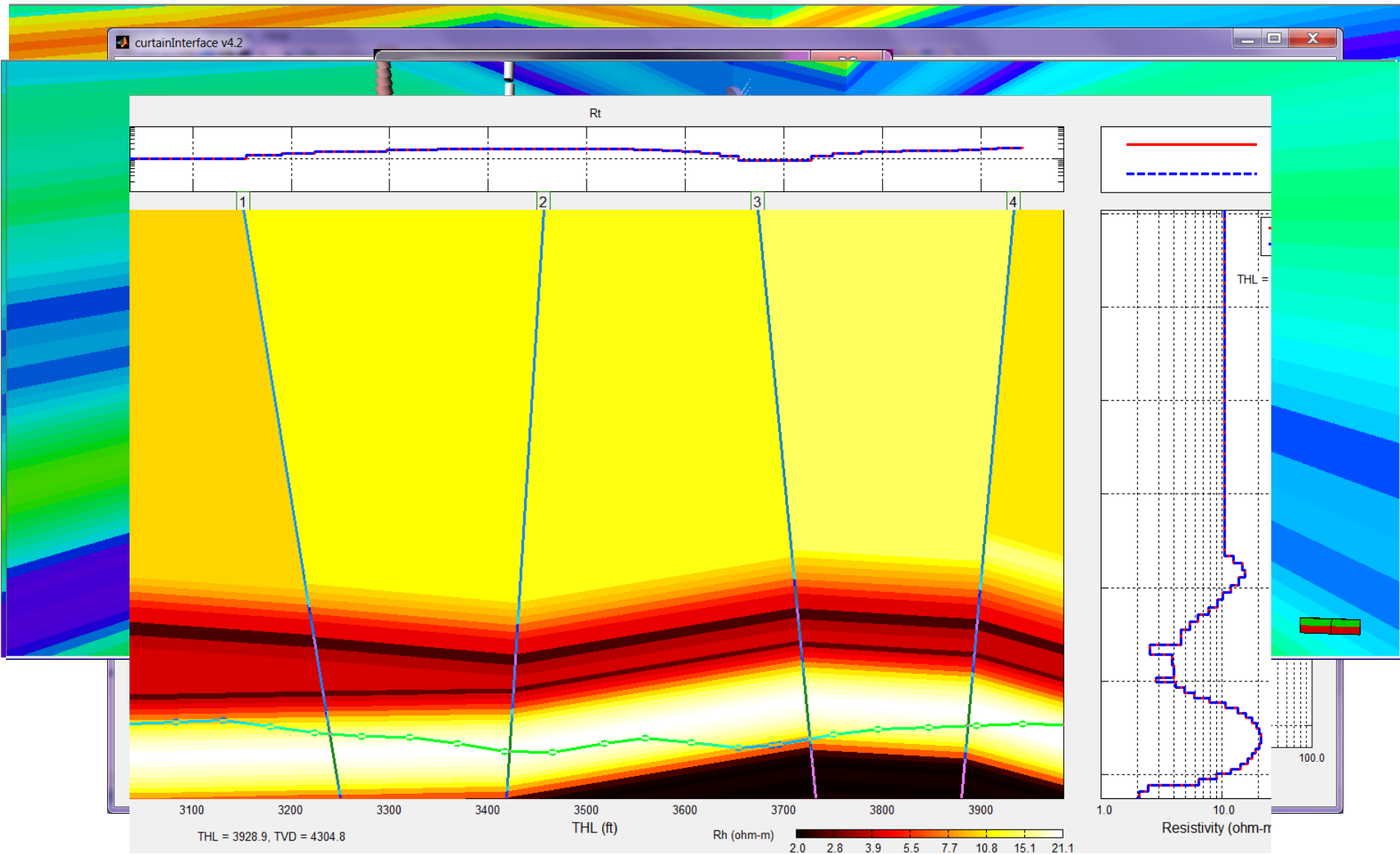
# Propagation Of Changes In Model Geometry



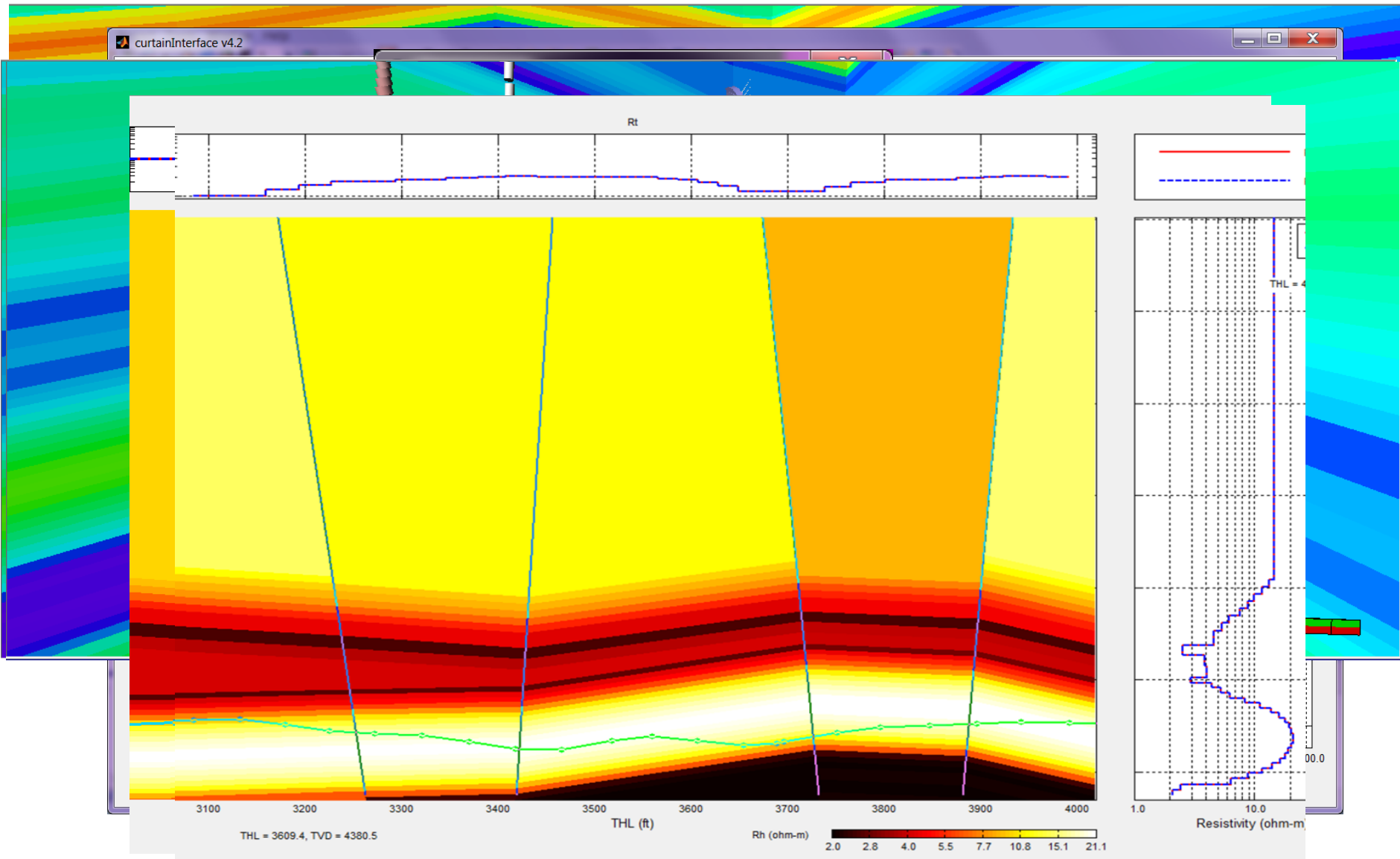
# Propagation Of Changes In Model Geometry



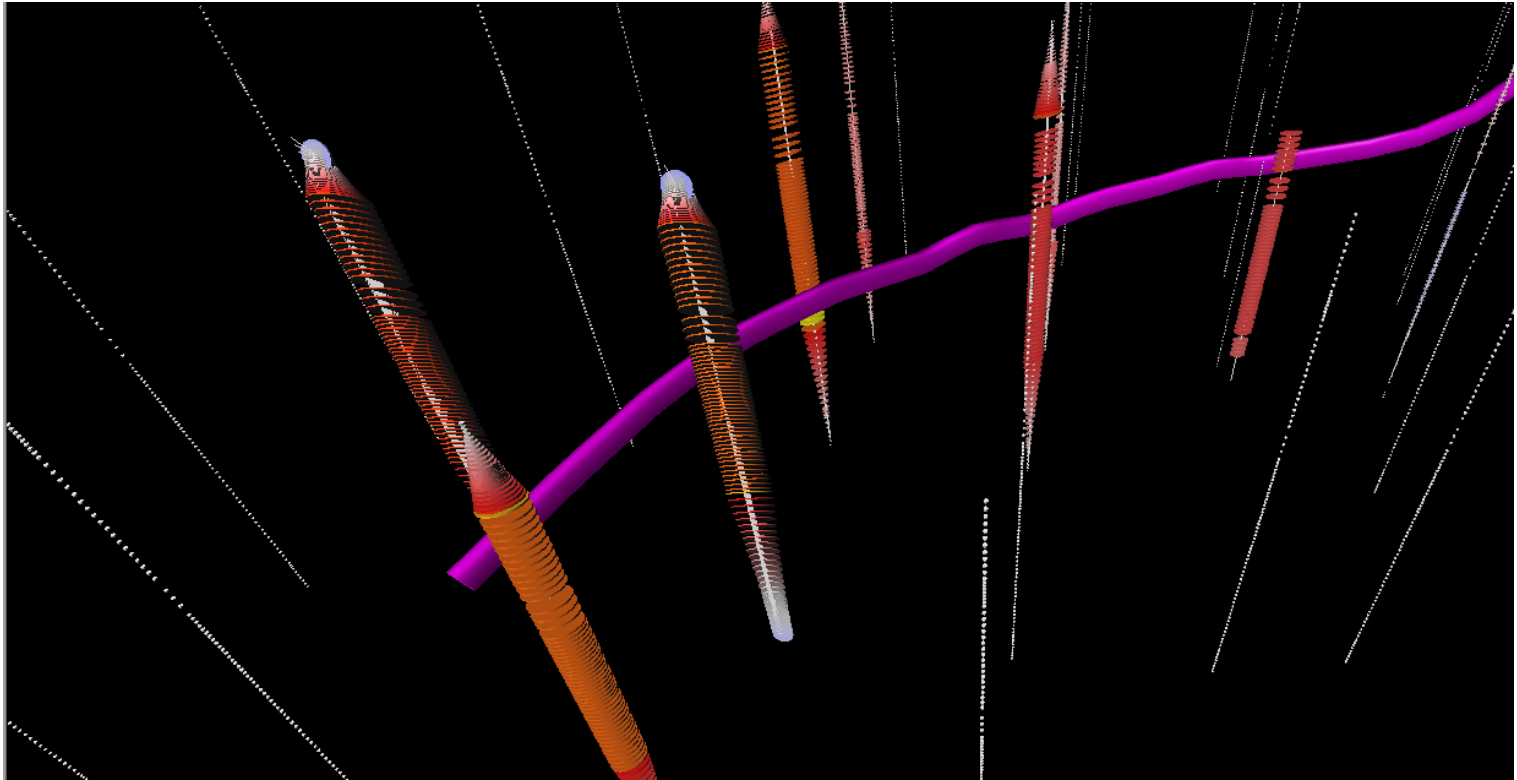
# Propagation Of Changes In Model Geometry



# Propagation Of Changes In Model Geometry

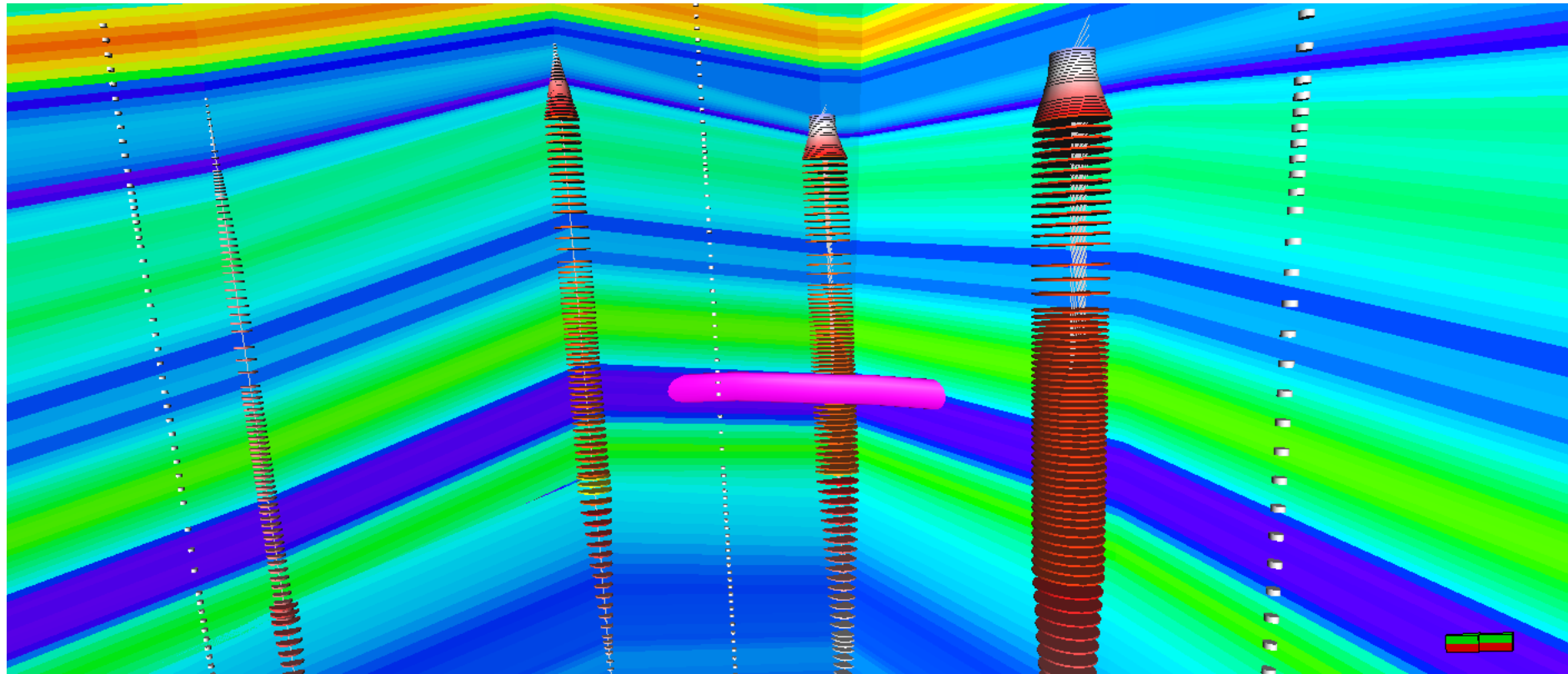


# Conveying the Model Delta



Size is moved distance  
Color is  $dZ$   
Angle is angle of movement  
Location is new location of node

# Conveying the Model Delta



Size is moved distance

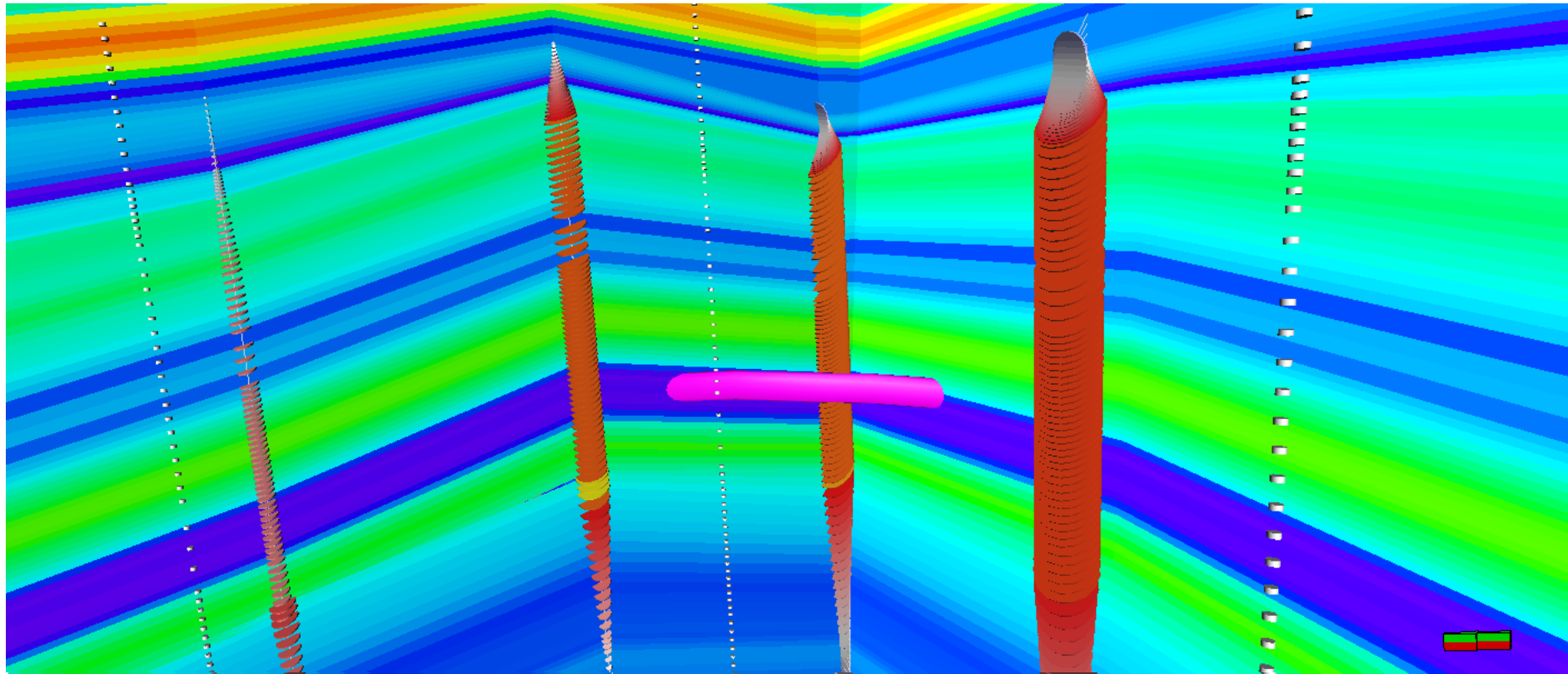
Color is  $dZ$

Angle is angle of movement

Location is new location of node

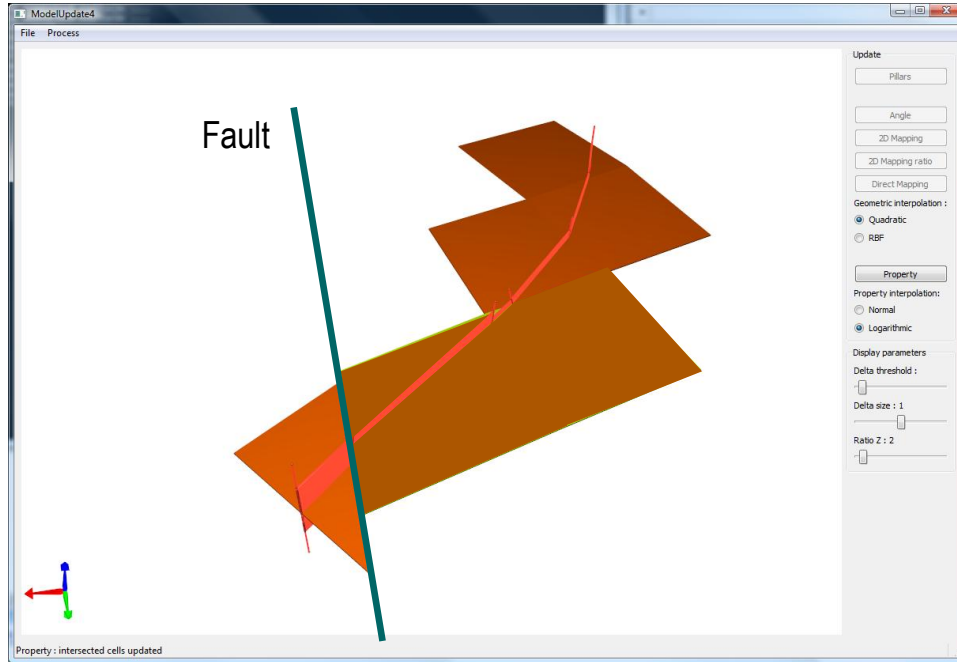


# Conveying the Model Delta

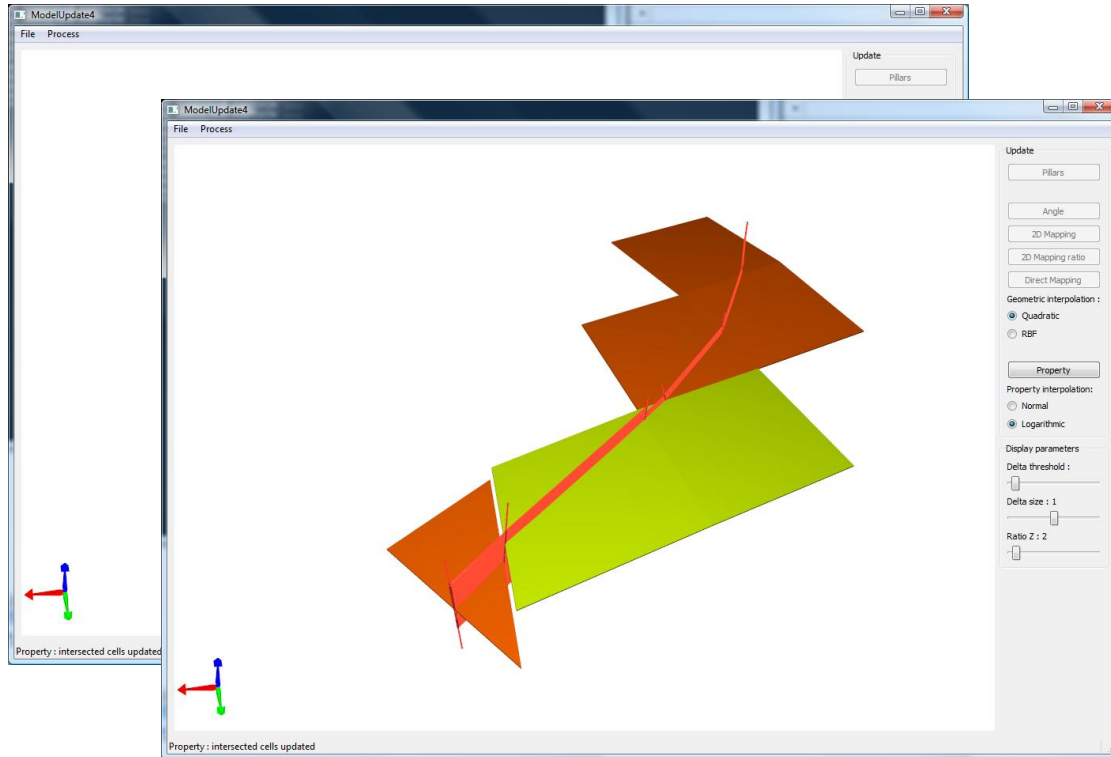


Size is moved distance  
Color is  $dZ$   
Angle is angle of movement  
Location is new location of node

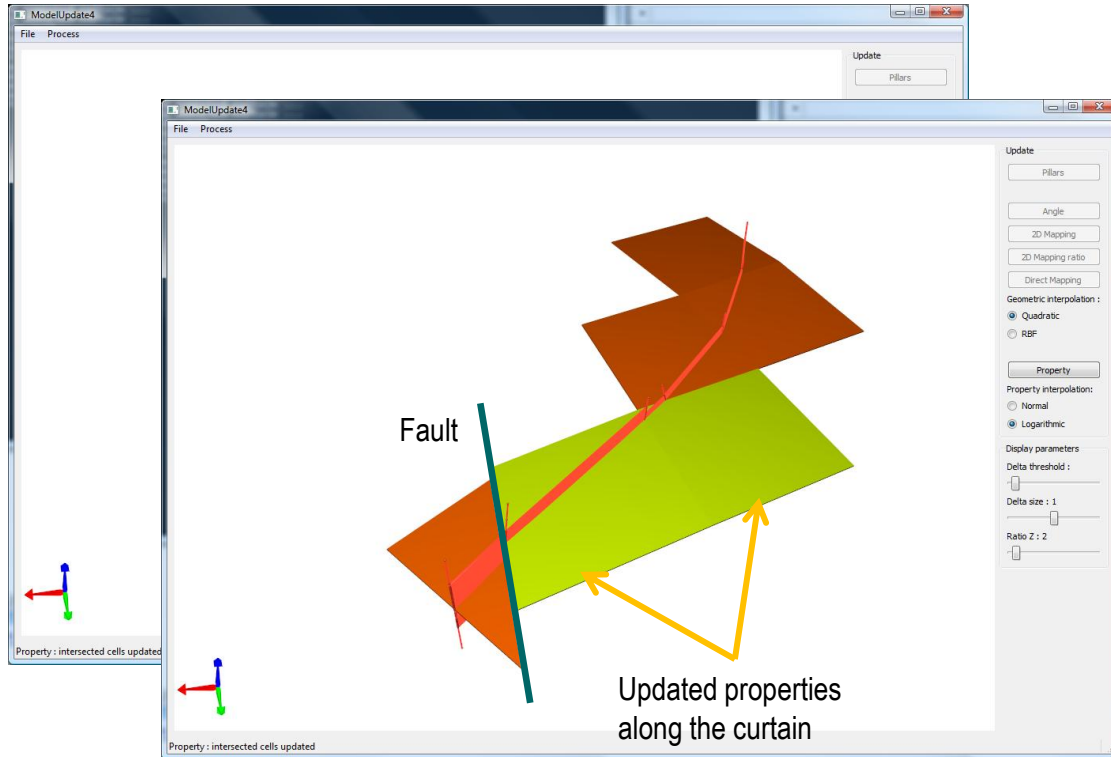
# Propagation Of Changes In Model Properties



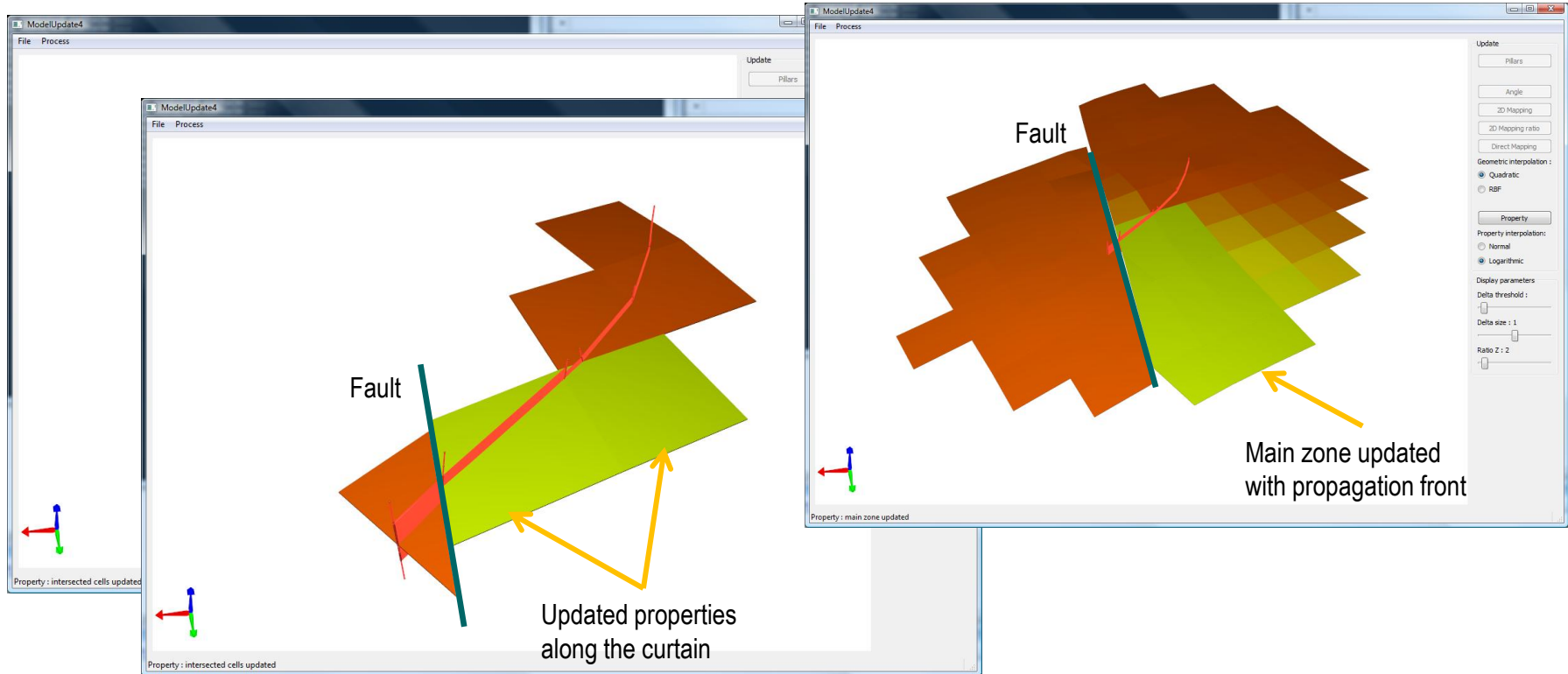
# Propagation Of Changes In Model Properties



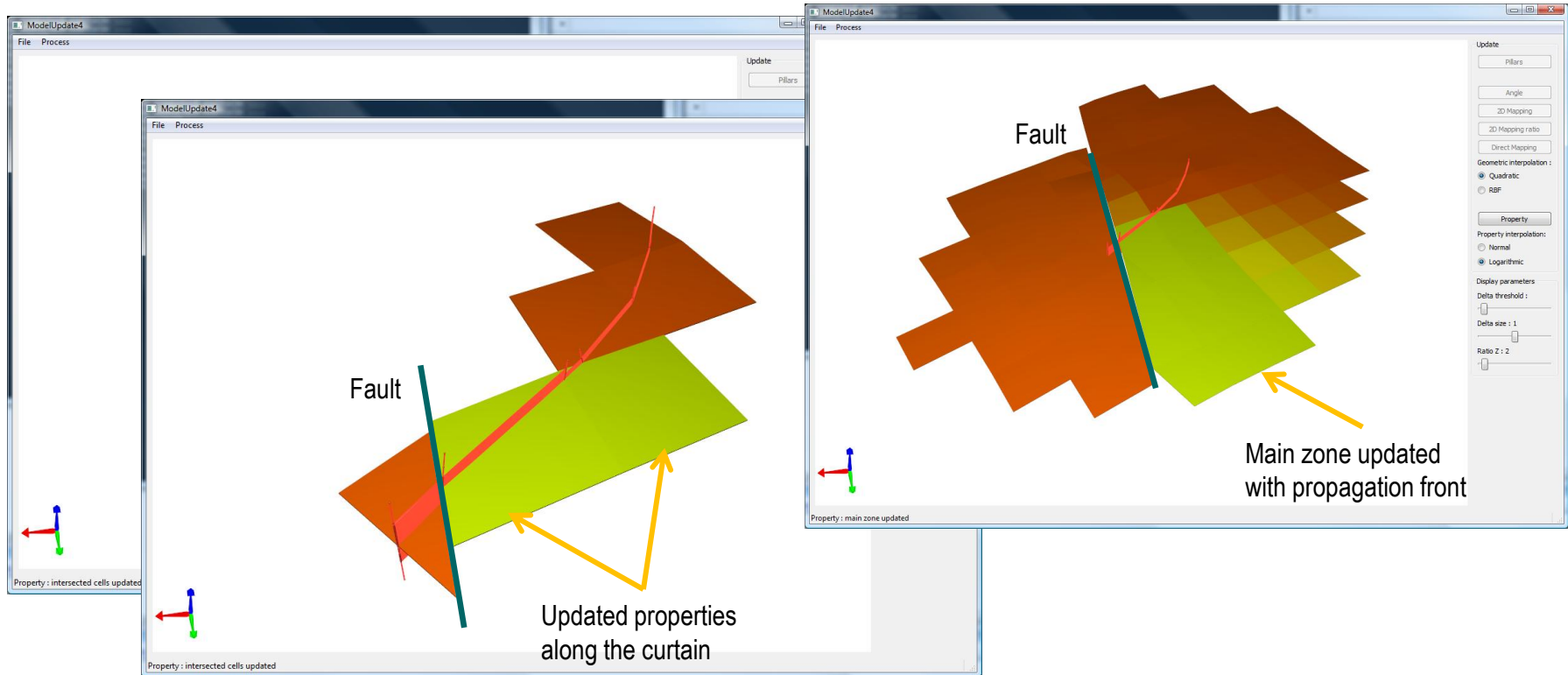
# Propagation Of Changes In Model Properties



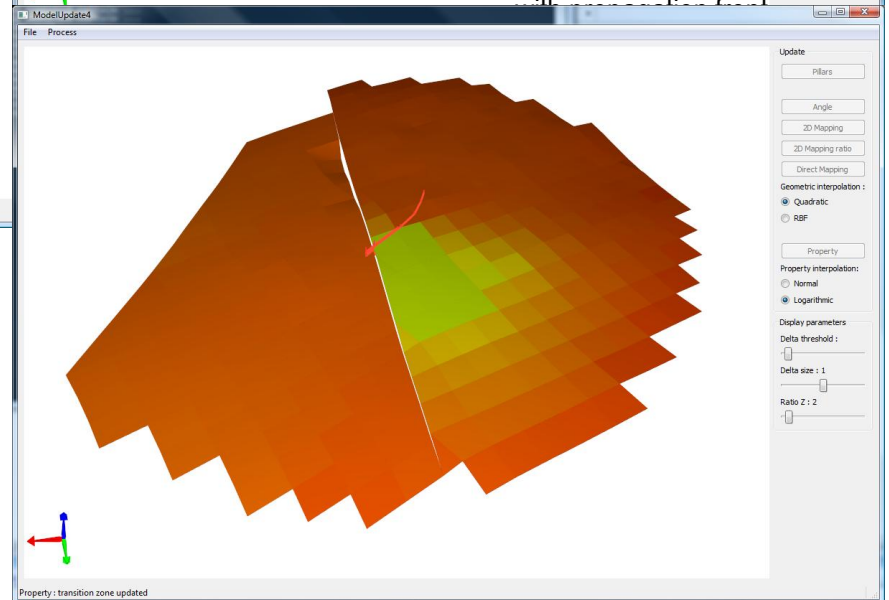
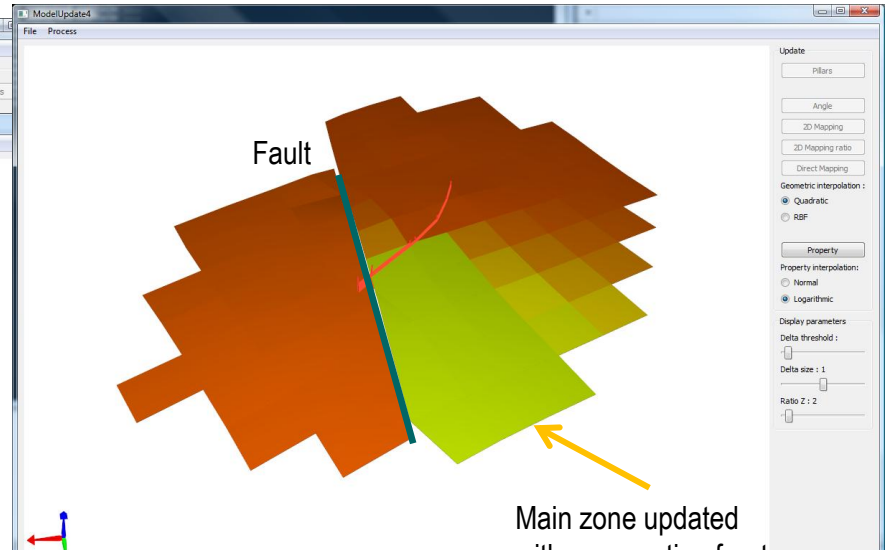
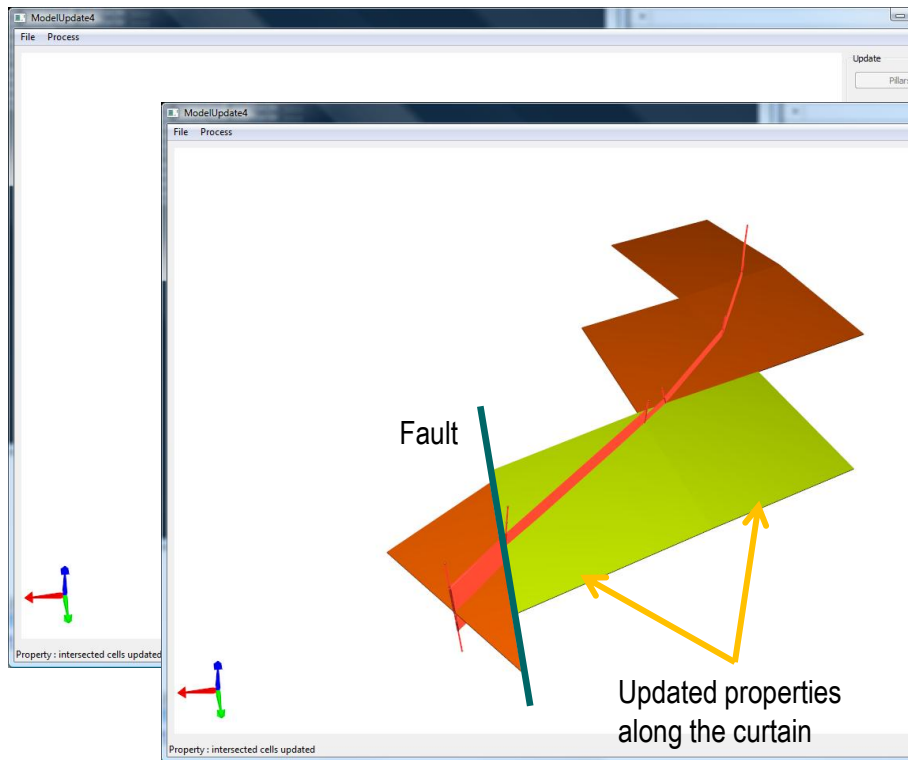
# Propagation Of Changes In Model Properties



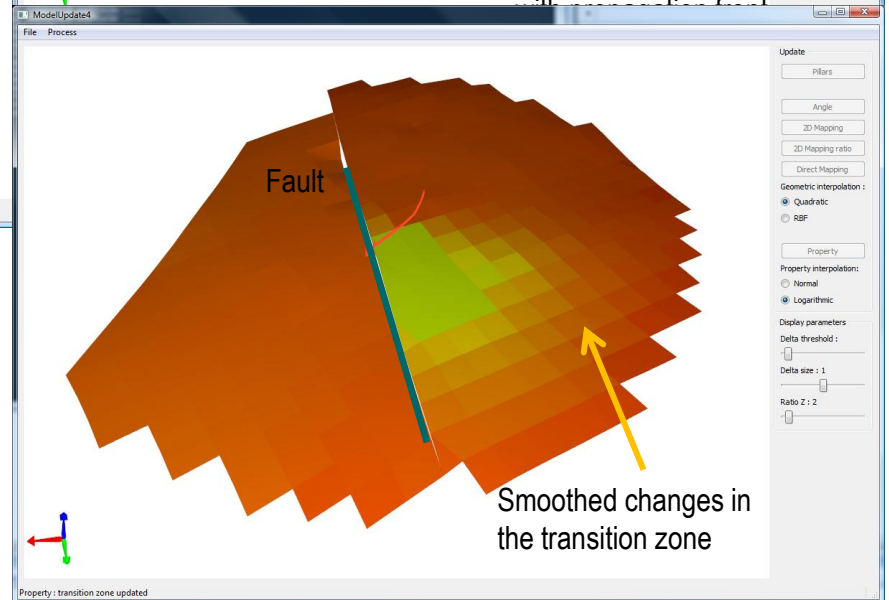
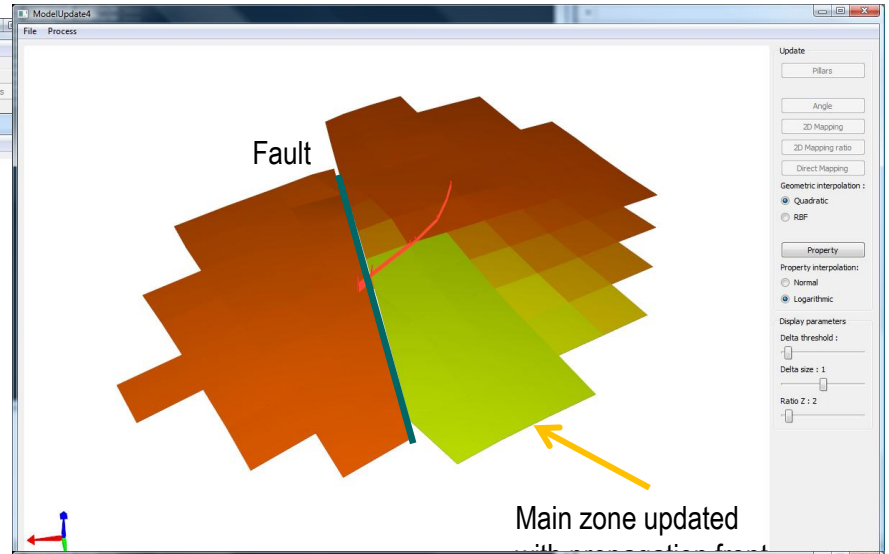
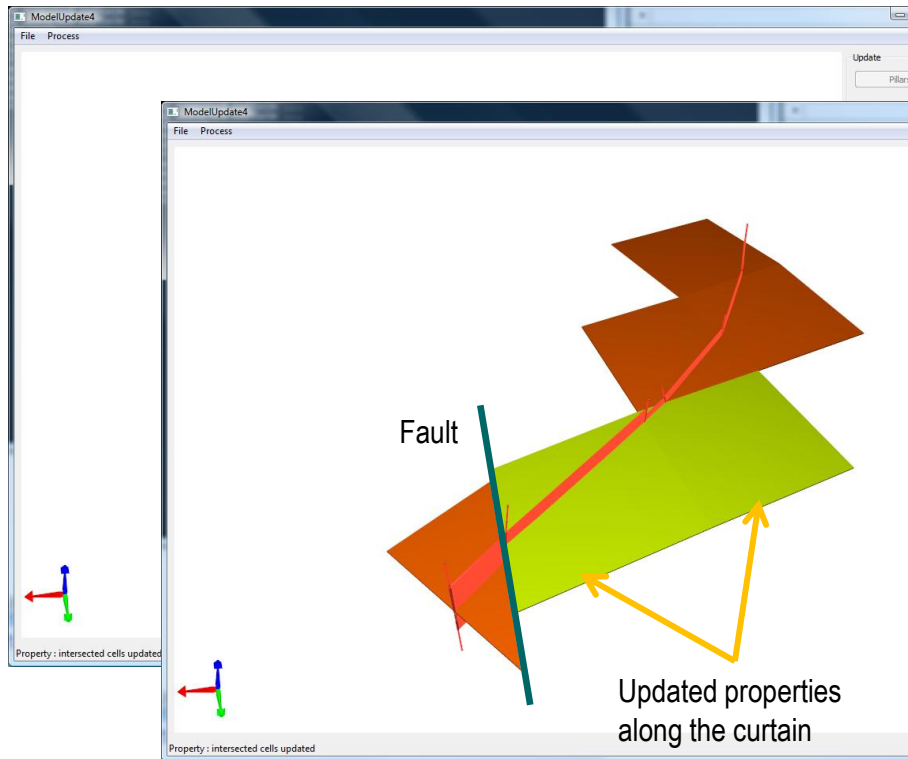
# Propagation Of Changes In Model Properties



# Propagation Of Changes In Model Properties

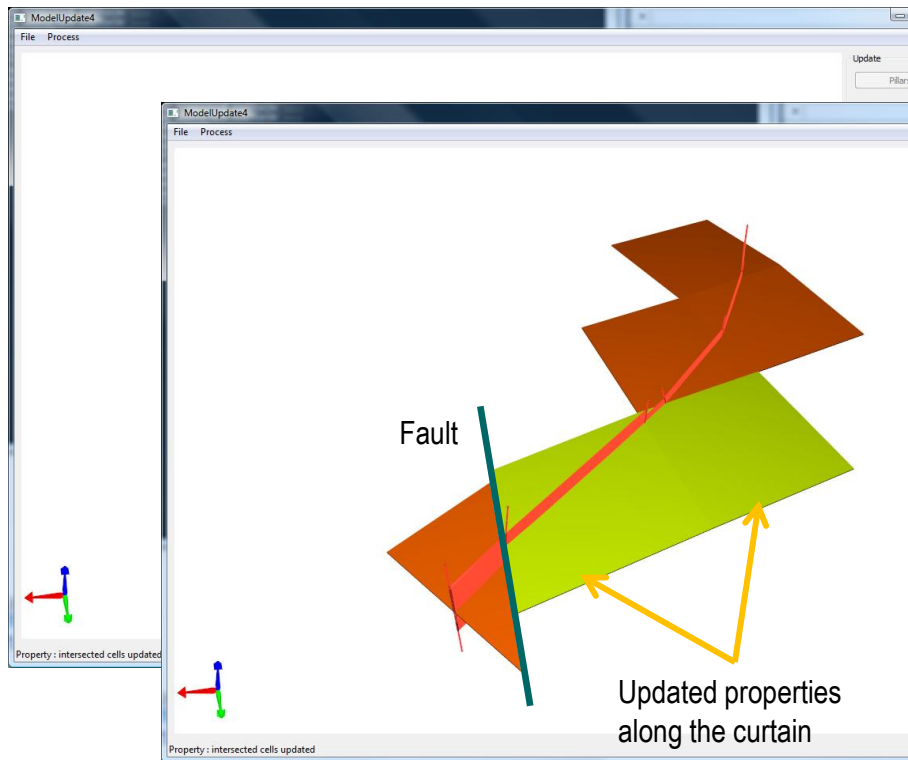


# Propagation Of Changes In Model Properties

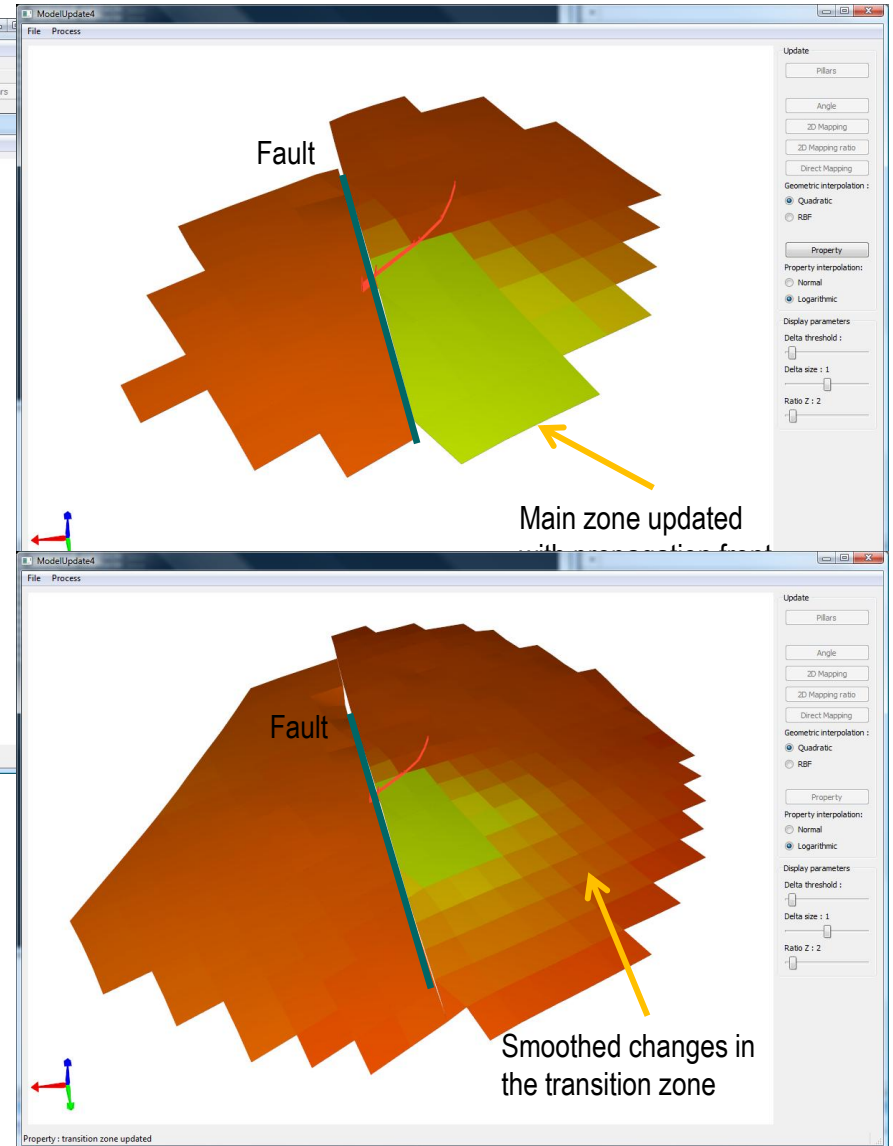




# Propagation Of Changes In Model Properties

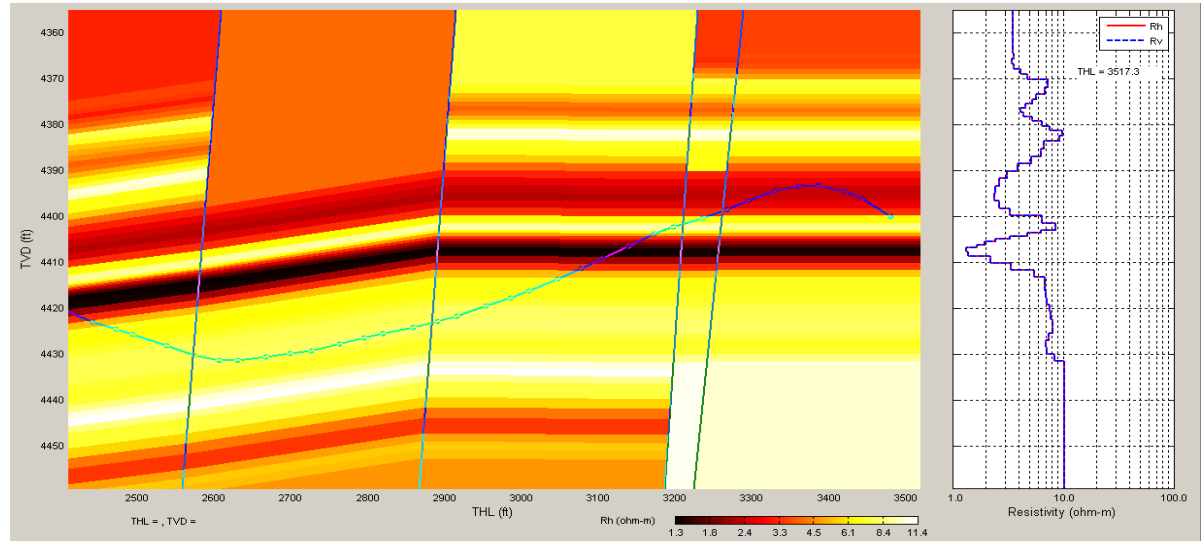


Changes applied layer by layer



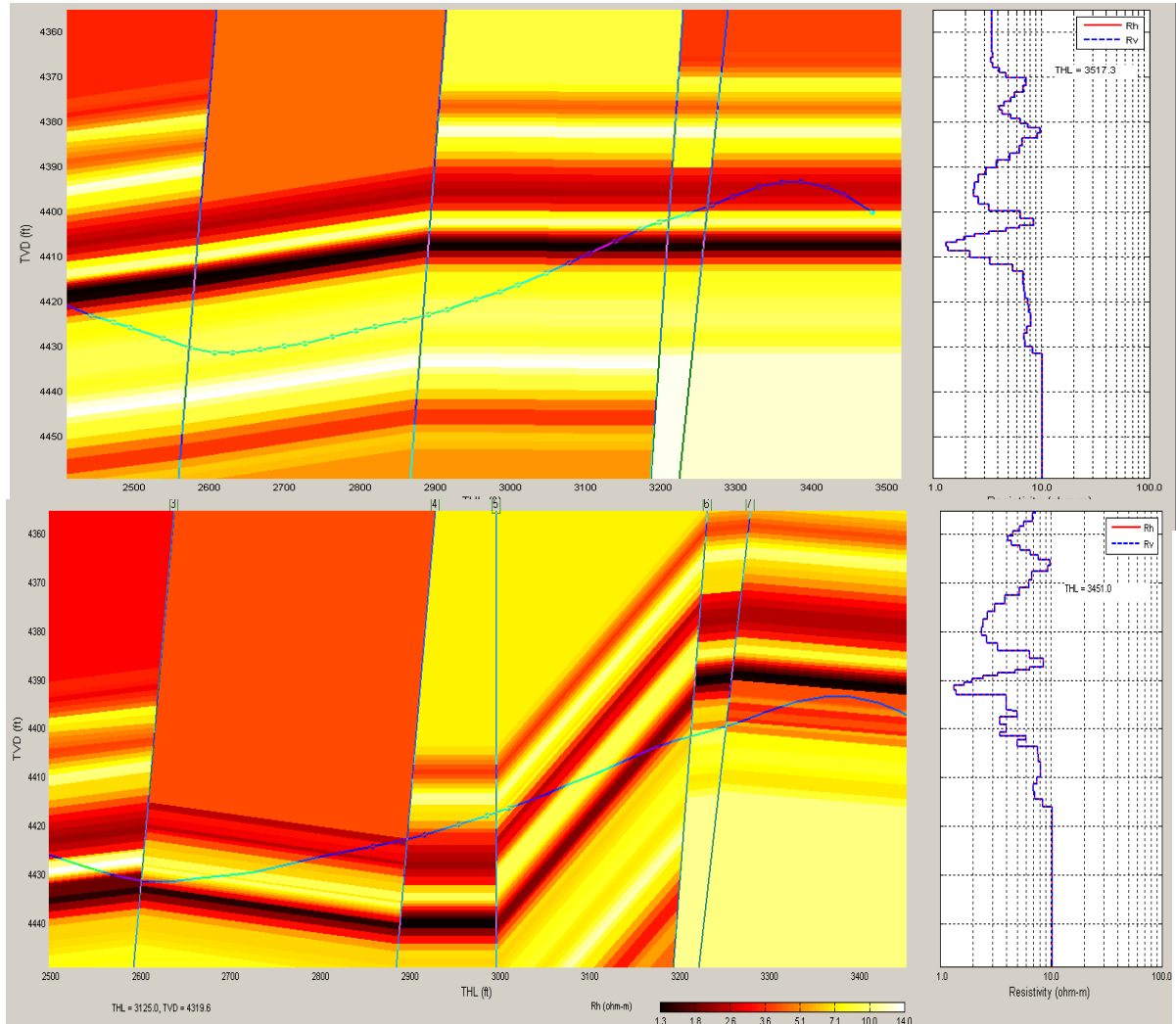
# Application: Lateral Change in Reservoir Structure Based on LWD Propagation Measurements

Initial model based on seismic and vertical well updated by changing dip with minimal profile change



# Application: Lateral Change in Reservoir Structure Based on LWD Propagation Measurements

Initial model based on seismic and vertical well updated by changing dip with minimal profile change



# Summary

- Proven feasibility of automated geomodel update based on well log modeling and inversion
- Physics-based log modeling and inversion to reduce the subjectivity in interpretation
- HPC infrastructure enables routine 2D & 3D log modeling and inversion
- Services-based platform for prototyping new HA/HZ FE and 3D well placement workflows
- Successfully deployed to process hundreds of HZ wells in a giant field study
- Future integration with geomodels: multi-scale, multi-physics, time-lapse