# Integration and Upscaling of Geophysical and Well-Log Data to Develop Reservoir Flow Models: The State-of-Practice in the Petroleum Industry


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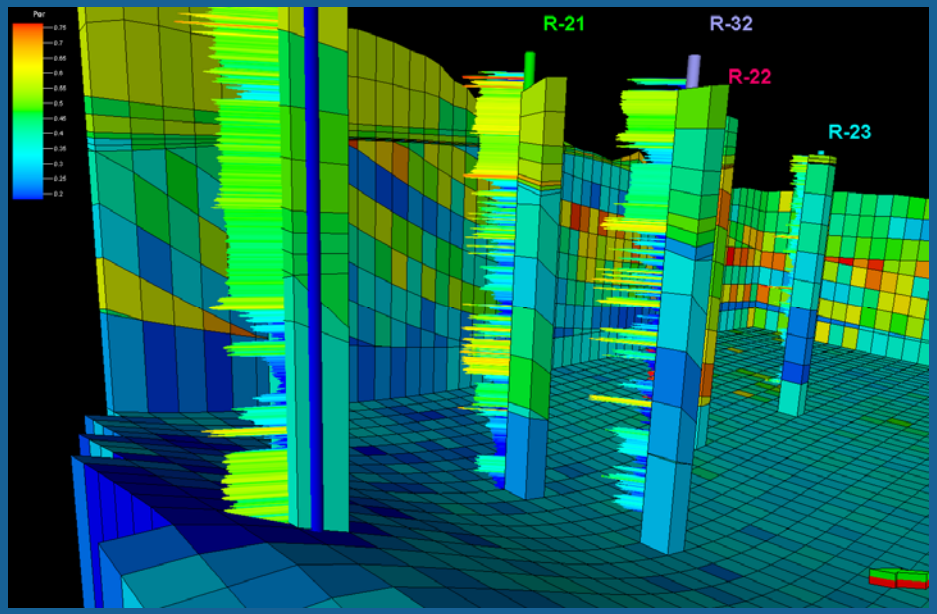



**ERSP Fall PI Meeting**
**October 23–25, 2006 Oak Ridge, TN**


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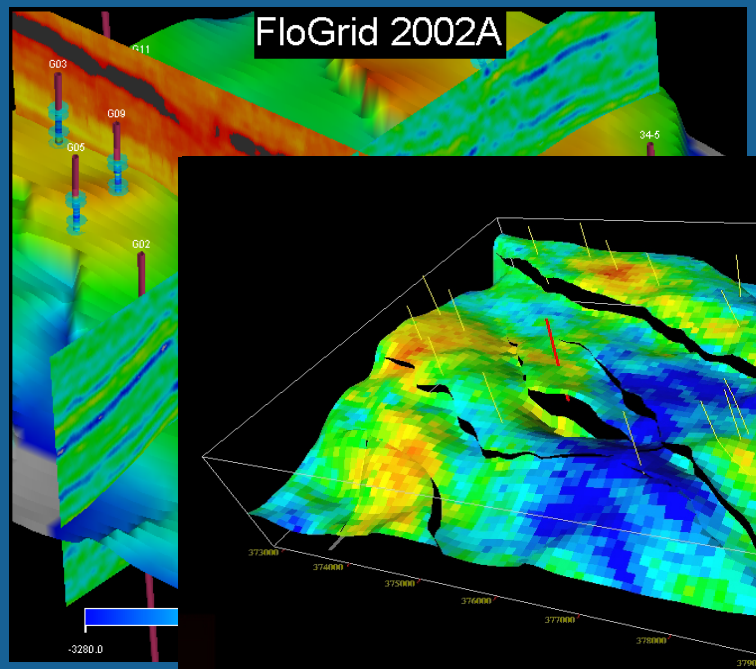
# Presentation Outline

- Overview of Reservoir Modeling Workflow
- Geological Modeling
  - Multi-well analysis
  - Seismic analysis
  - Structural framework
  - Property modeling – (1) facies, (2) petrophysical
  - Uncertainty
- Reservoir Simulation Modeling
  - Grid generation and property upscaling
  - Simulation engines
  - Uncertainty and optimization
- Closing Remarks – application to subsurface water resources

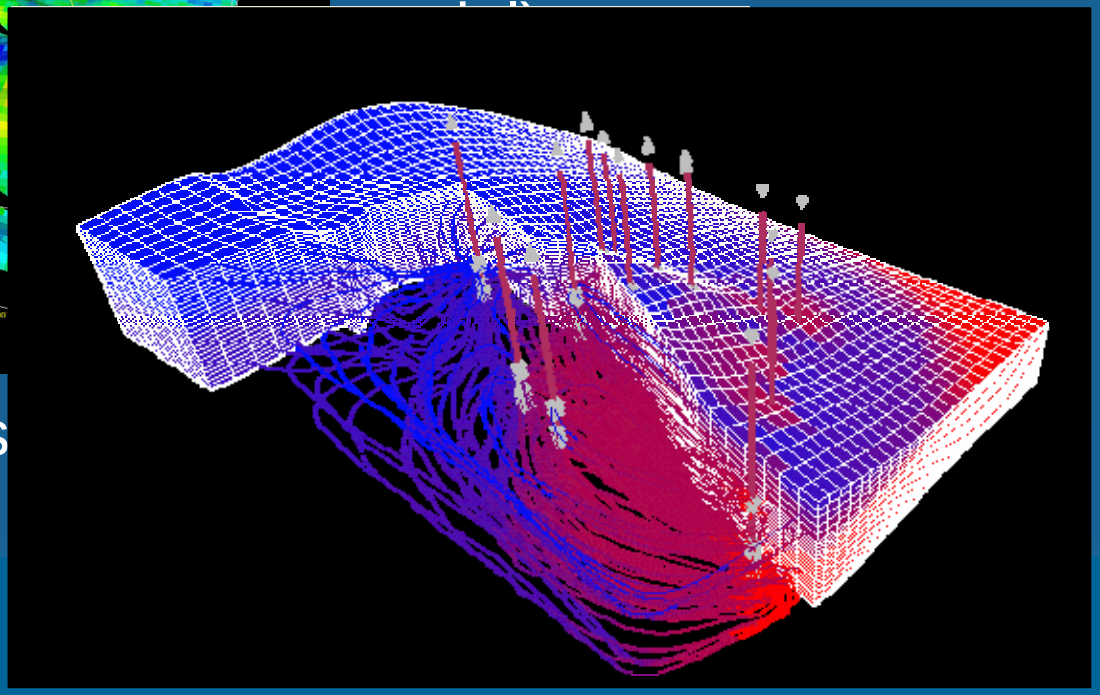
# 3-D Reservoir Model Development – General Workflow




Integrate data to generate surfaces (structural framework)



Populate layers with properties (geologic



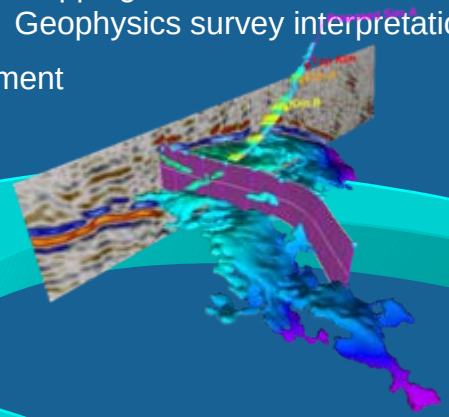
Predict reservoir conditions for production scenarios

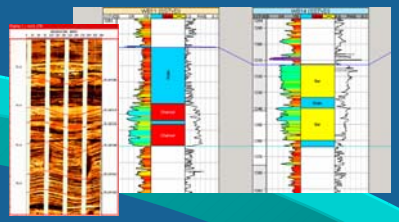
# Optimized Reservoir Modeling Workflow

Surface imaging
Mapping
Geophysics survey interpretation

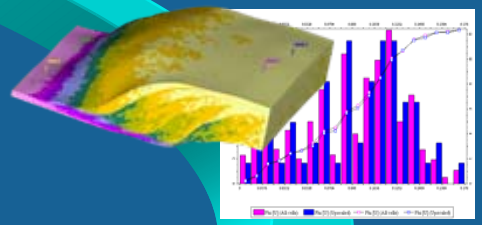
Log interpretation
Well correlation
Surface identification and mapping

Data input
Information management
GIS database

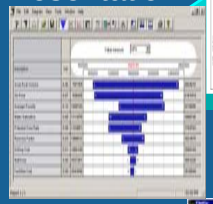


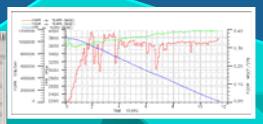


Data spatial analysis
Facies modelling
Fault modelling
Fracture modelling
Well test analysis

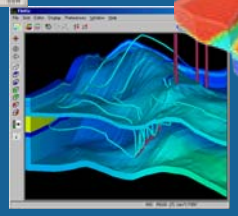


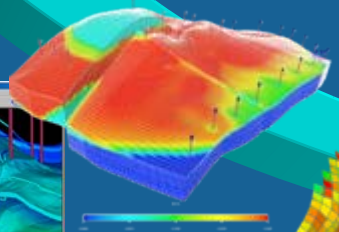
Calibration
History match
Sensitivity analysis
Post processing
Presentation

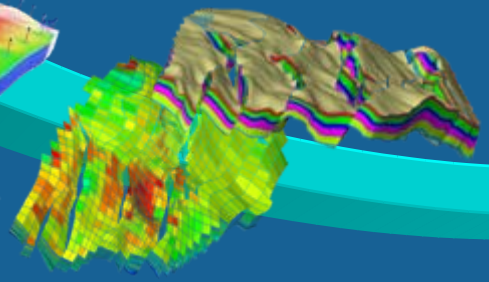


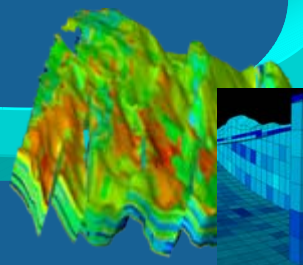


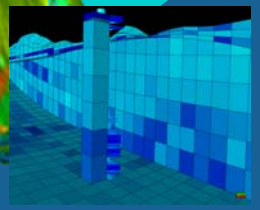
Eclipse











3D flow and mass transport simulation
Multi-phase, density dependent flow
Fully-coupled geomechanics
Modeling of geochemical reactions
Streamline simulation

3D geological model
Geological conceptual model
3D flow property model
Upscaling to simulation grid

Uncertainty analysis
Upscaling of processes
Reservoir property population

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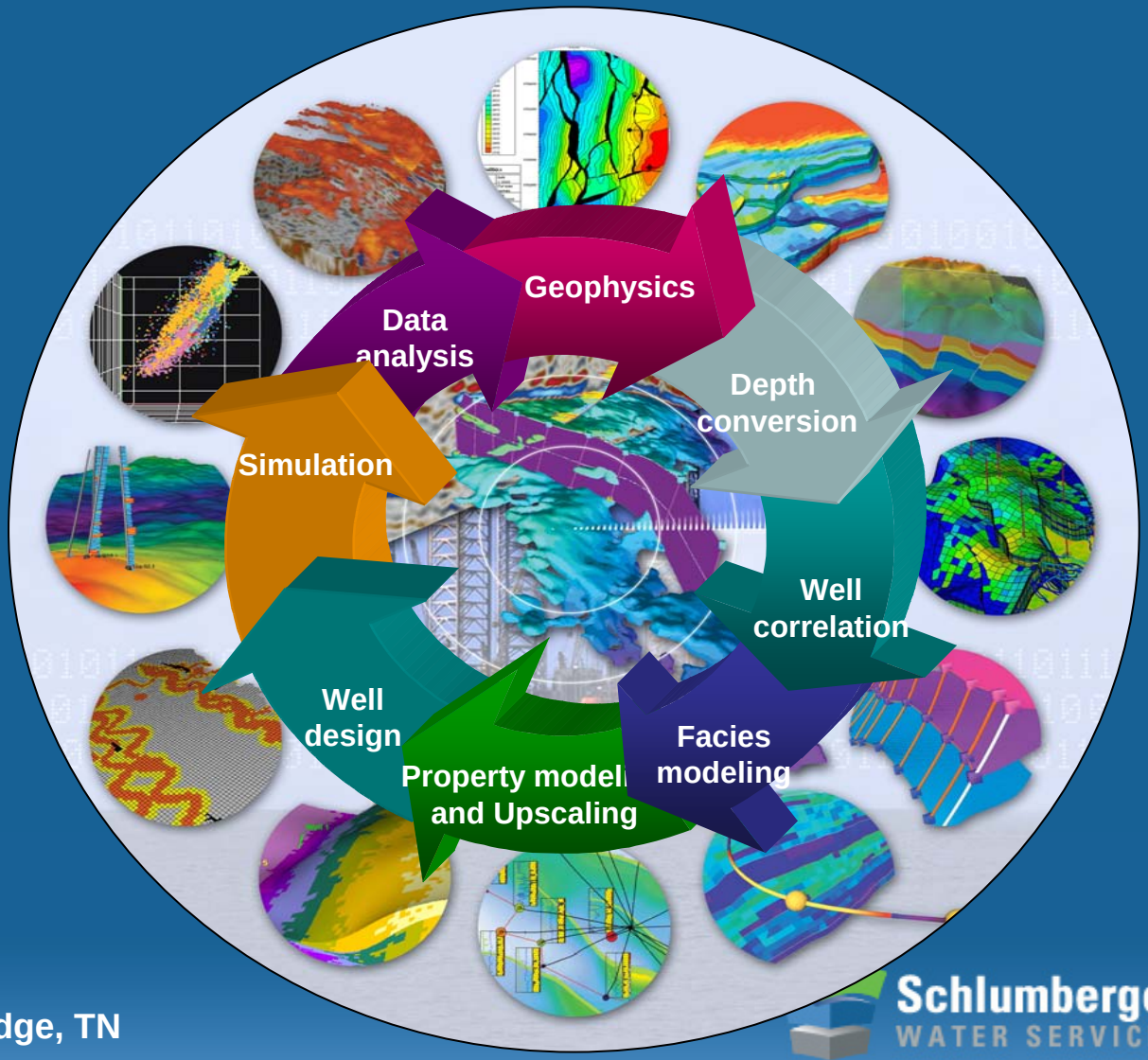
# Integrated Reservoir Modeling Environment

- Combines wide array of powerful analysis and visualization tools
- Complete workflow from seismic to reservoir simulation
- Integrates all data types
- Easily and quickly updated



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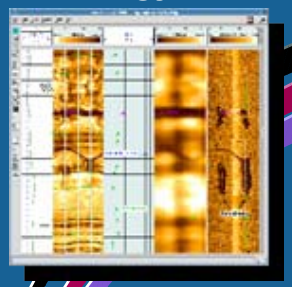
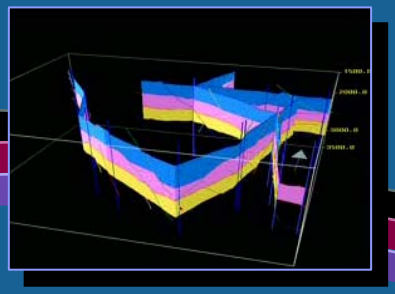
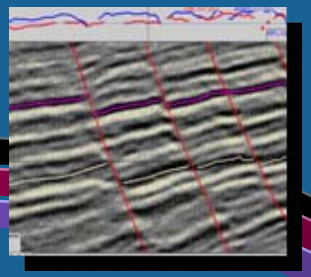
Borehole Geology



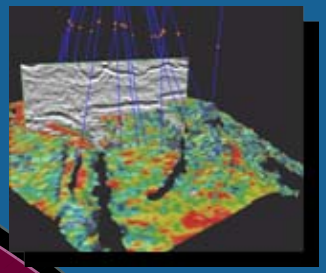
Geology



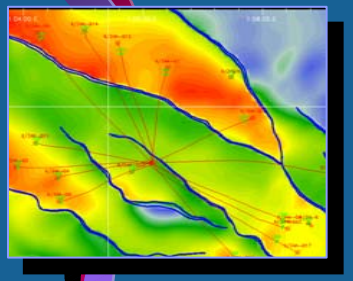
Geophysics



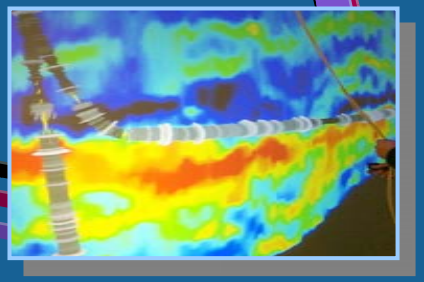
3D Interpretation & Visualization



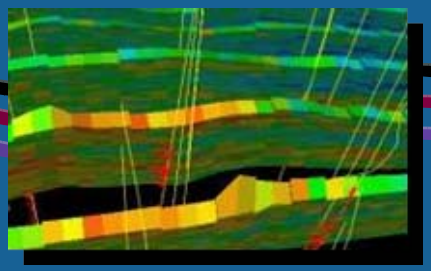
Mapping



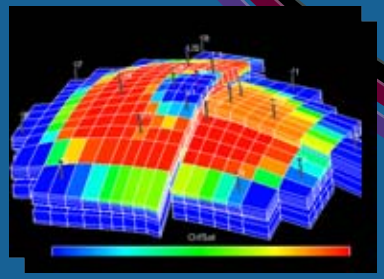
Drilling



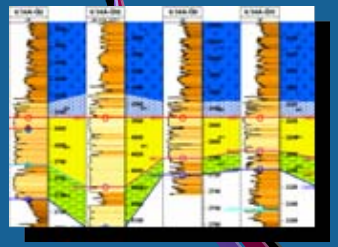
Modeling

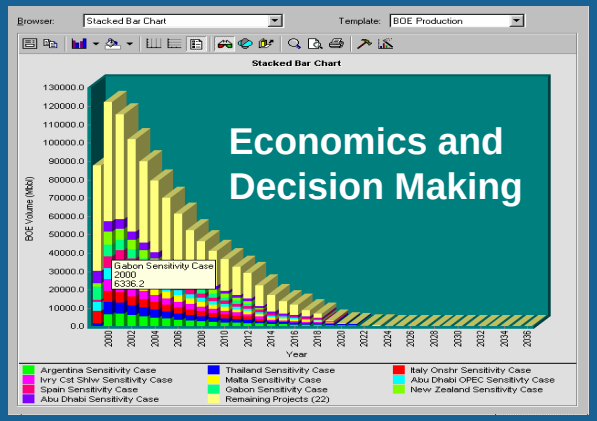


Simulation



Petrophysics






Economics and Decision Making

# Presentation Outline

- Overview of Reservoir Modeling Workflow
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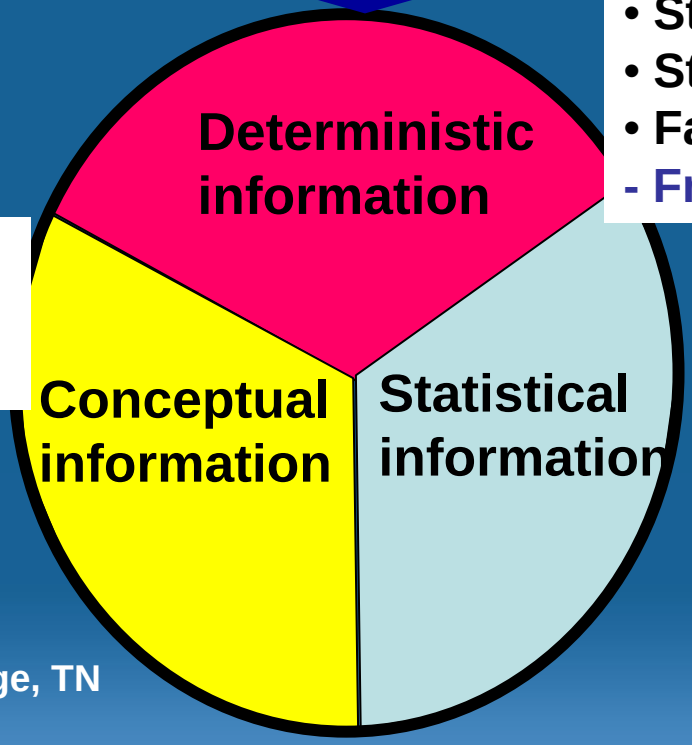
# What is a geological model and where does the data come from:

Well data | Seismic data | Production | Outcrops | Other geological studies

**Integrated study**




- Structure (horizon, fault)
- Stratigraphic correlation
- Facies images
- Framework

- Sedimentological model
- Facies description
- Connectivity

- Histogram
- Variogram
- Correlation
- Trend
- Variation



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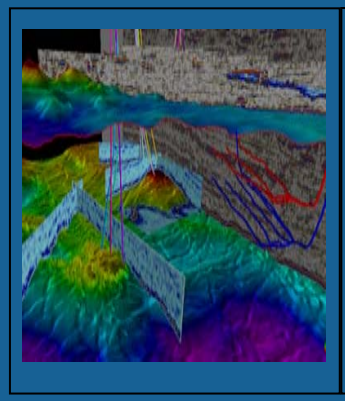
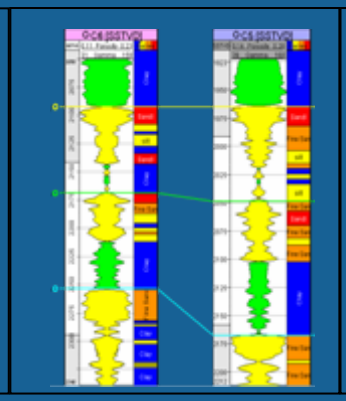
# Geological Modeling Workflow Tools (Petrel™)

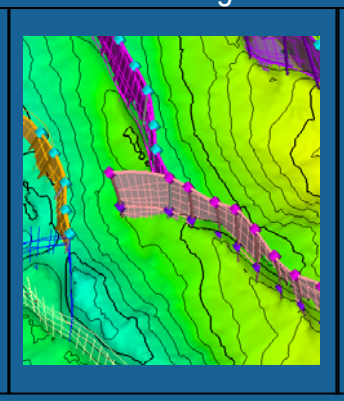
Seismic



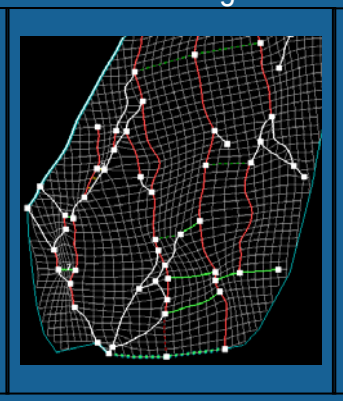
Well Correlation



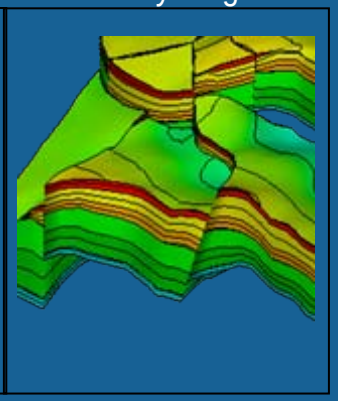
Fault Modeling



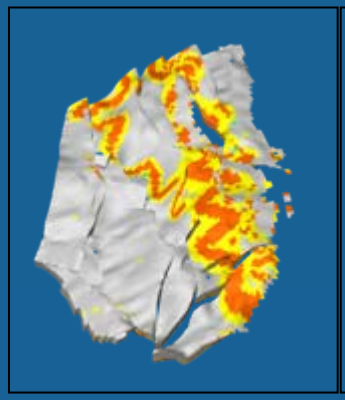
Pillar Gridding



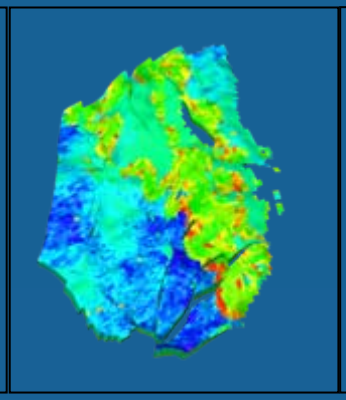
Zonation and Layering



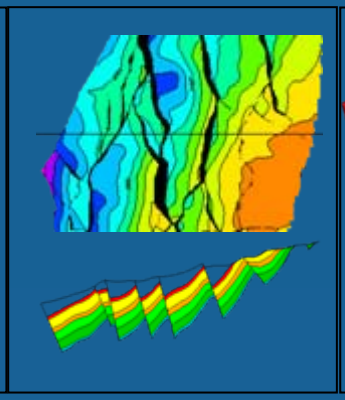
Facies Modeling



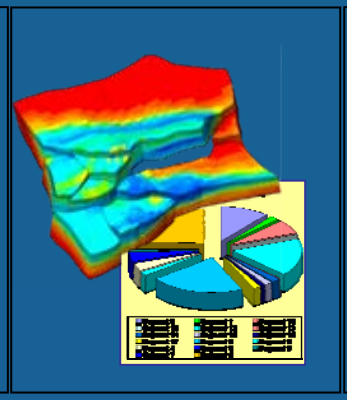
Petrophysical Modeling



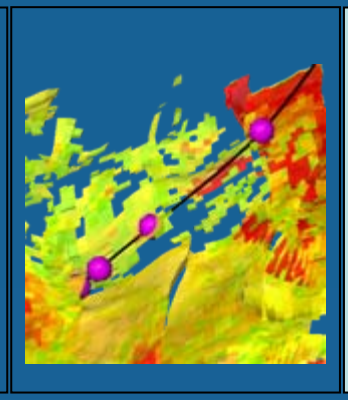
Plotting

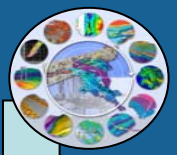


Volume Calculation



Well Design





Process Manager



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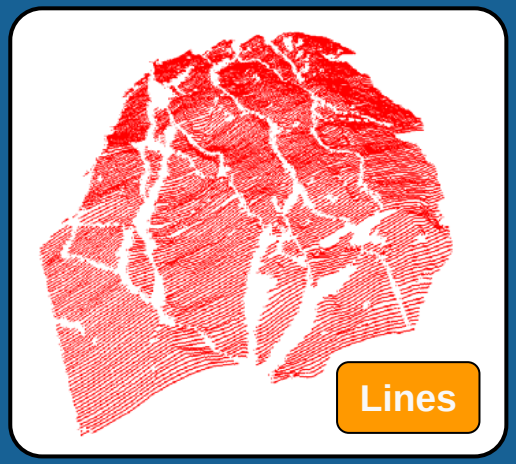
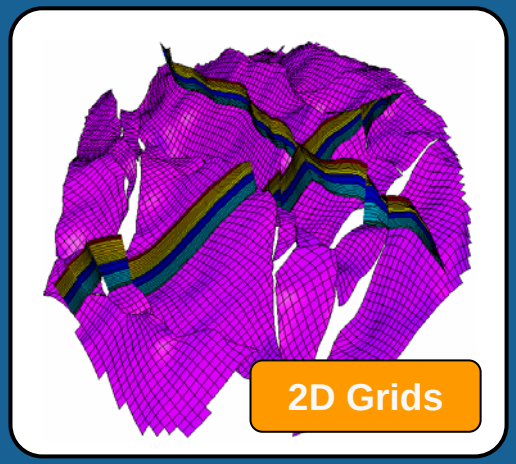
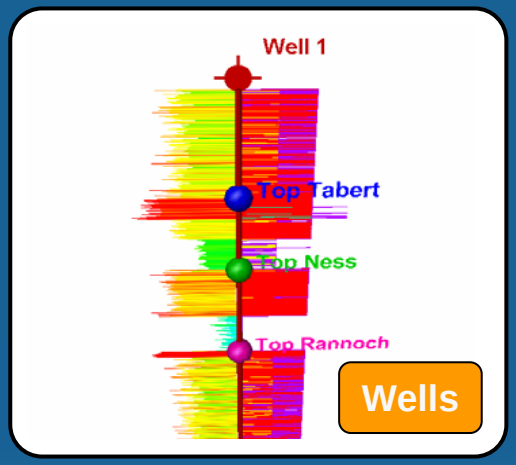
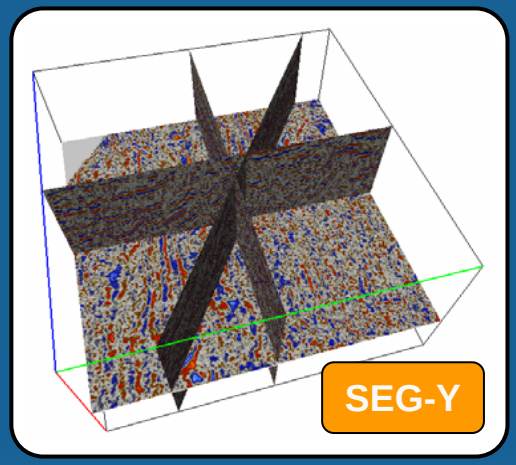
# Petrel Data Import

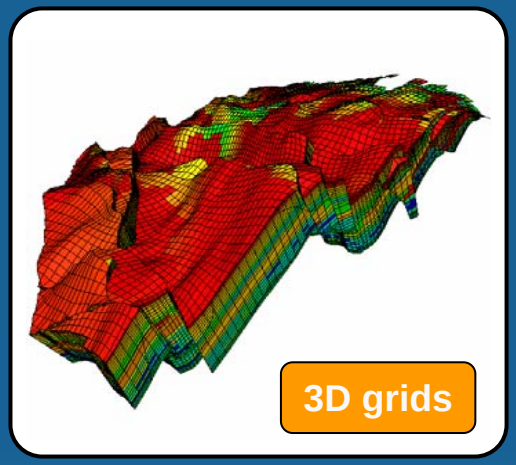
## File types



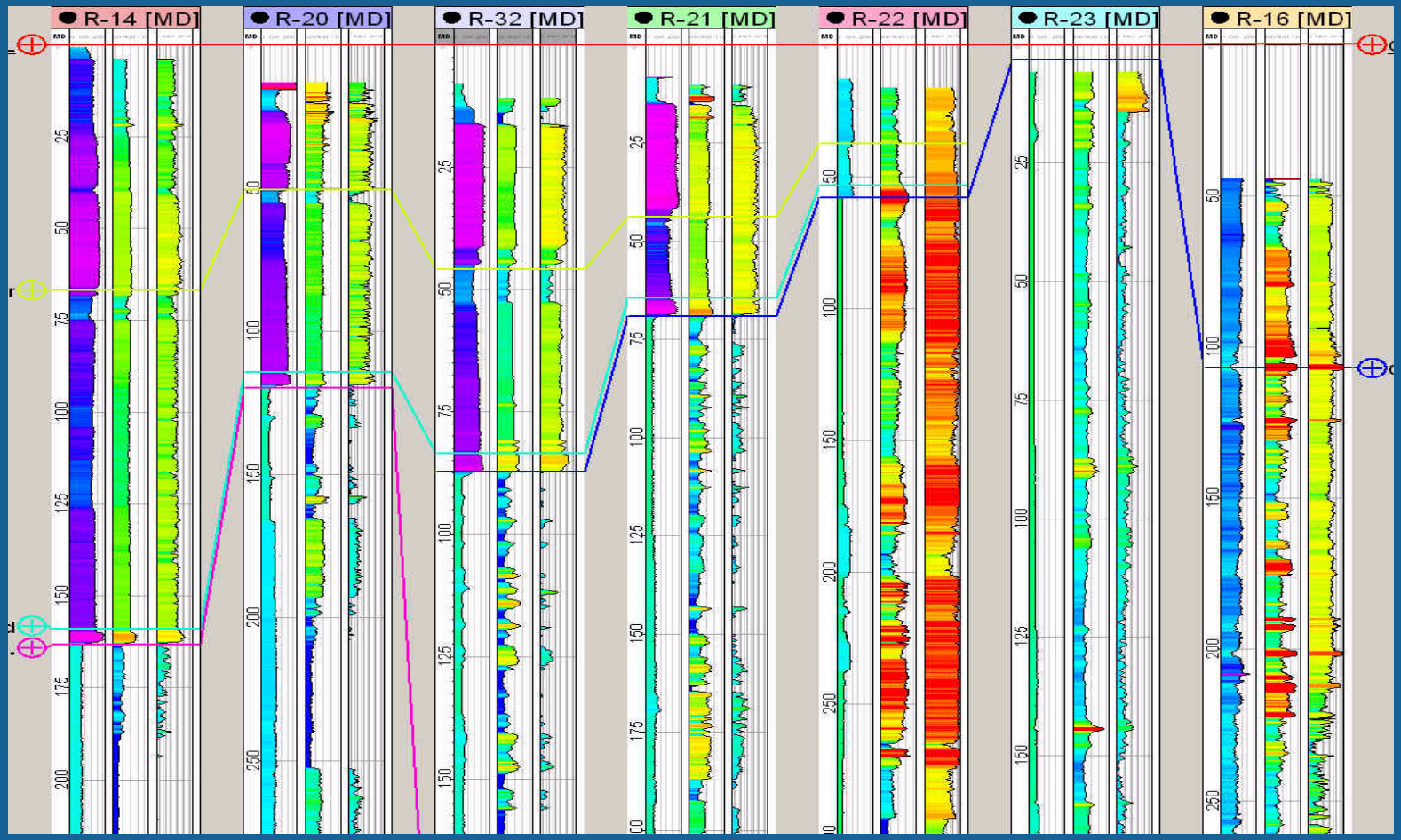


# Interactive Correlation of Markers Between Wells Using Geophysical Logs



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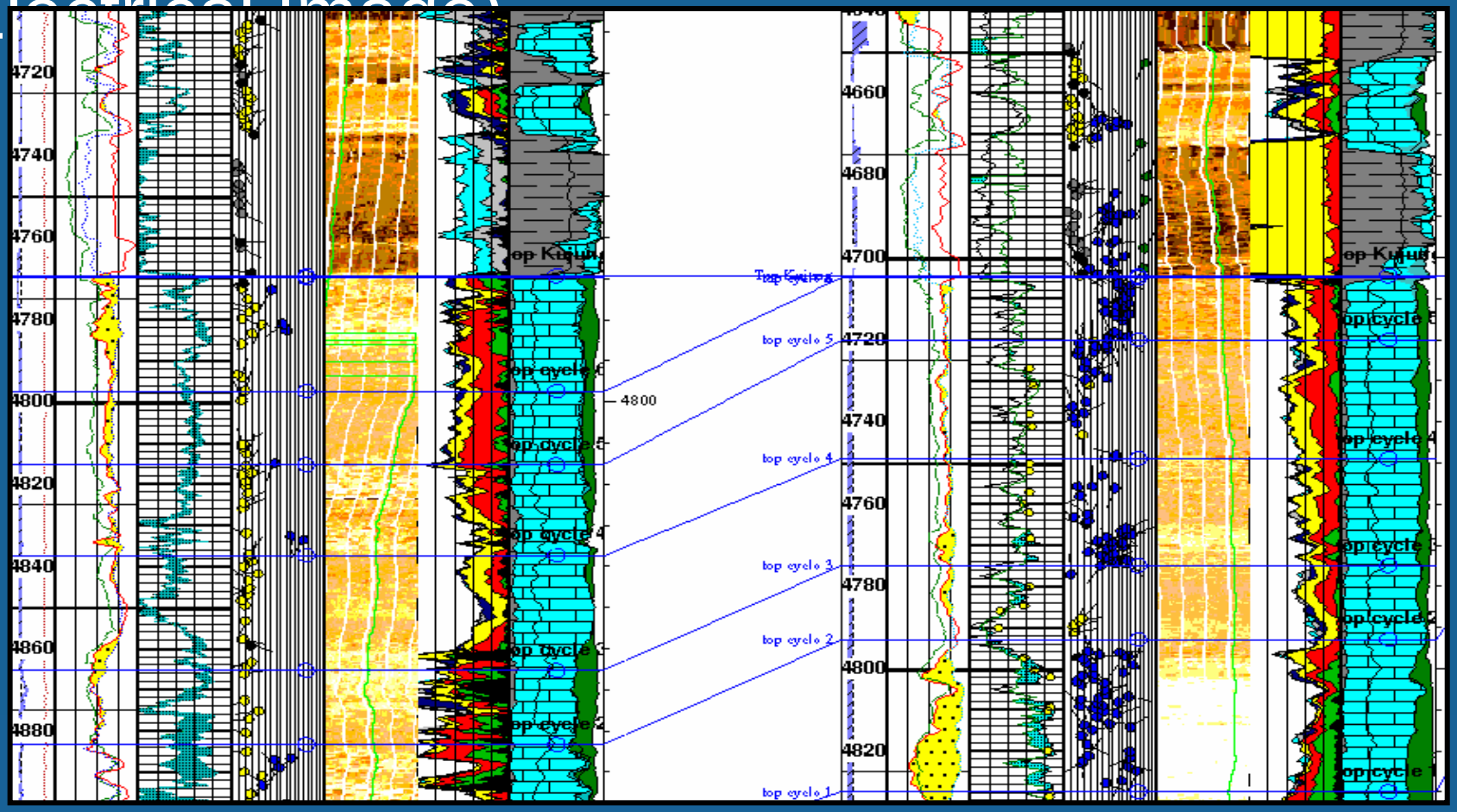
# Interactive Correlation of Markers Between Wells Using Geophysical Logs (With Electrical Image)



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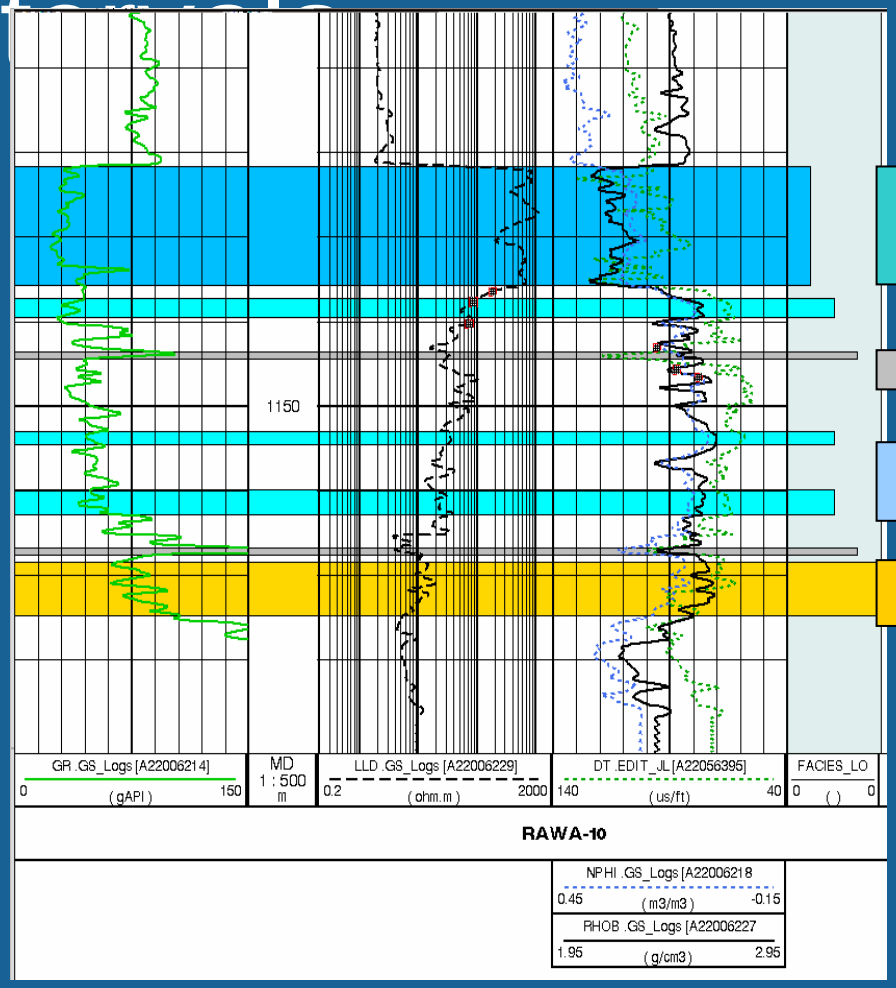
# Facies Zonation From Logs

- “Electrofacies” classification
- Define facies groups
  - Interactively by depth or cross-plot groupings of log responses
  - Automatically using multi-dimensional cluster analysis
  - Single or multiple wells
- Automatically define facies zones in other wells using (un)supervised neural network analysis

# Facies Definition Based on Depth Intervals




Porous Carb.

High GR-Styl.

Tight Carb.

Mud Carb.



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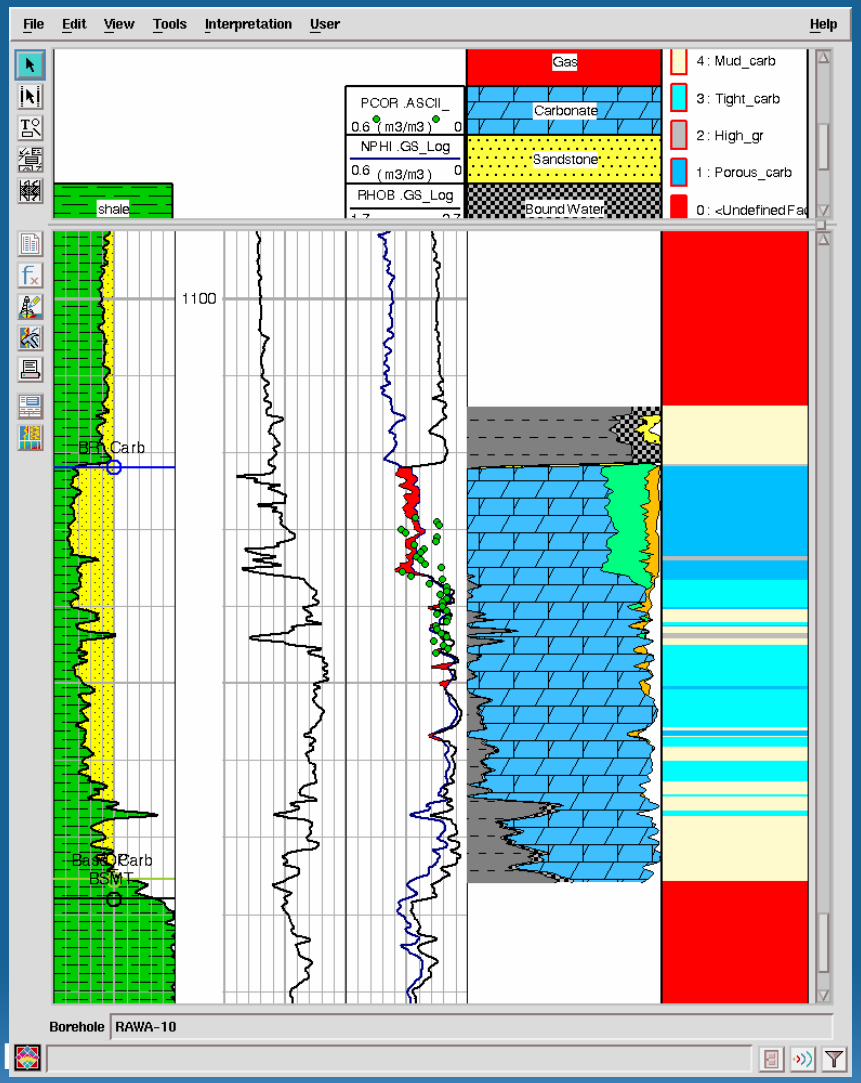
# Same Facies Automatically Identified and Zoned in Another Well



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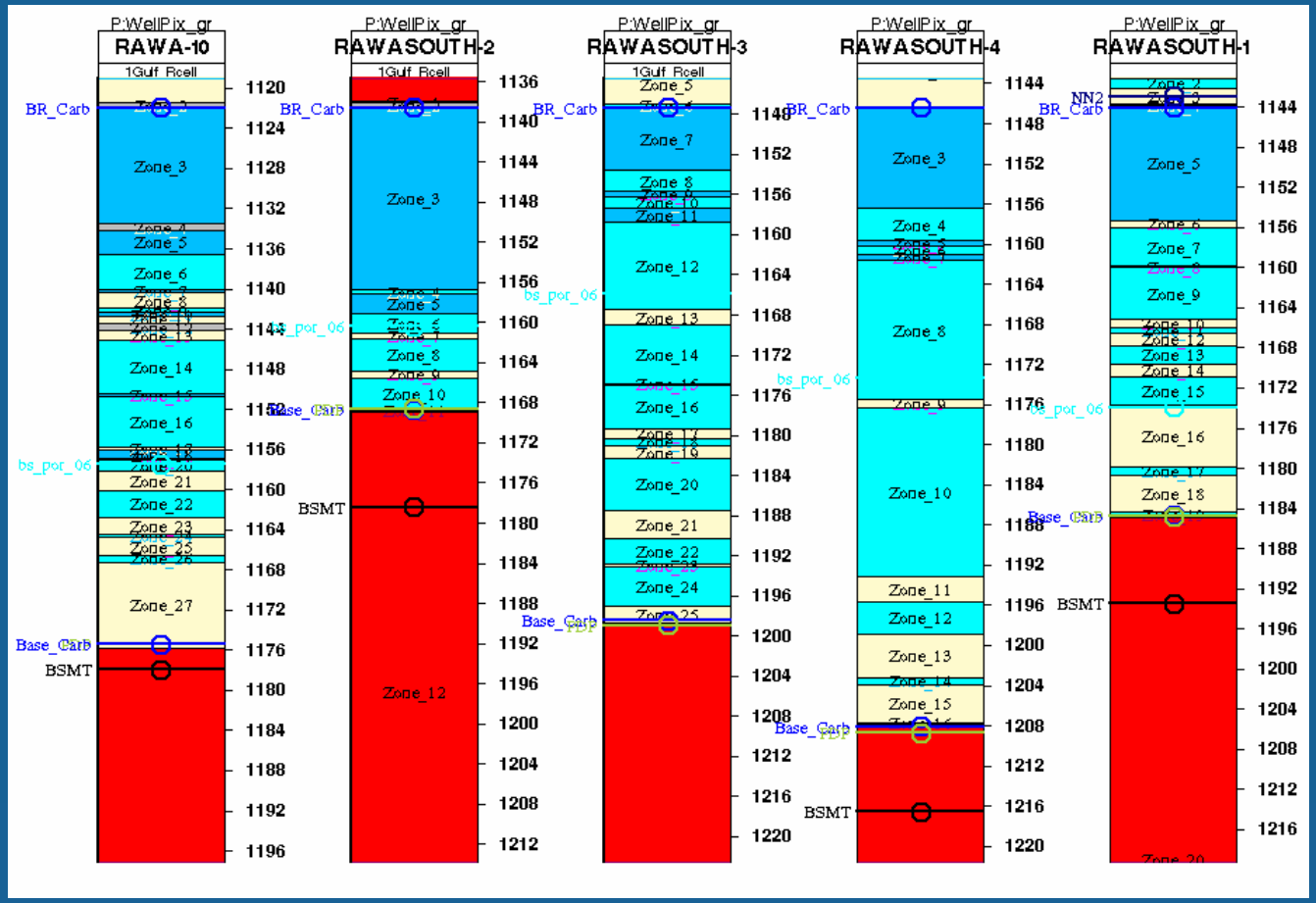
# Facies Automatically Zoned in All Wells and Correlations Made



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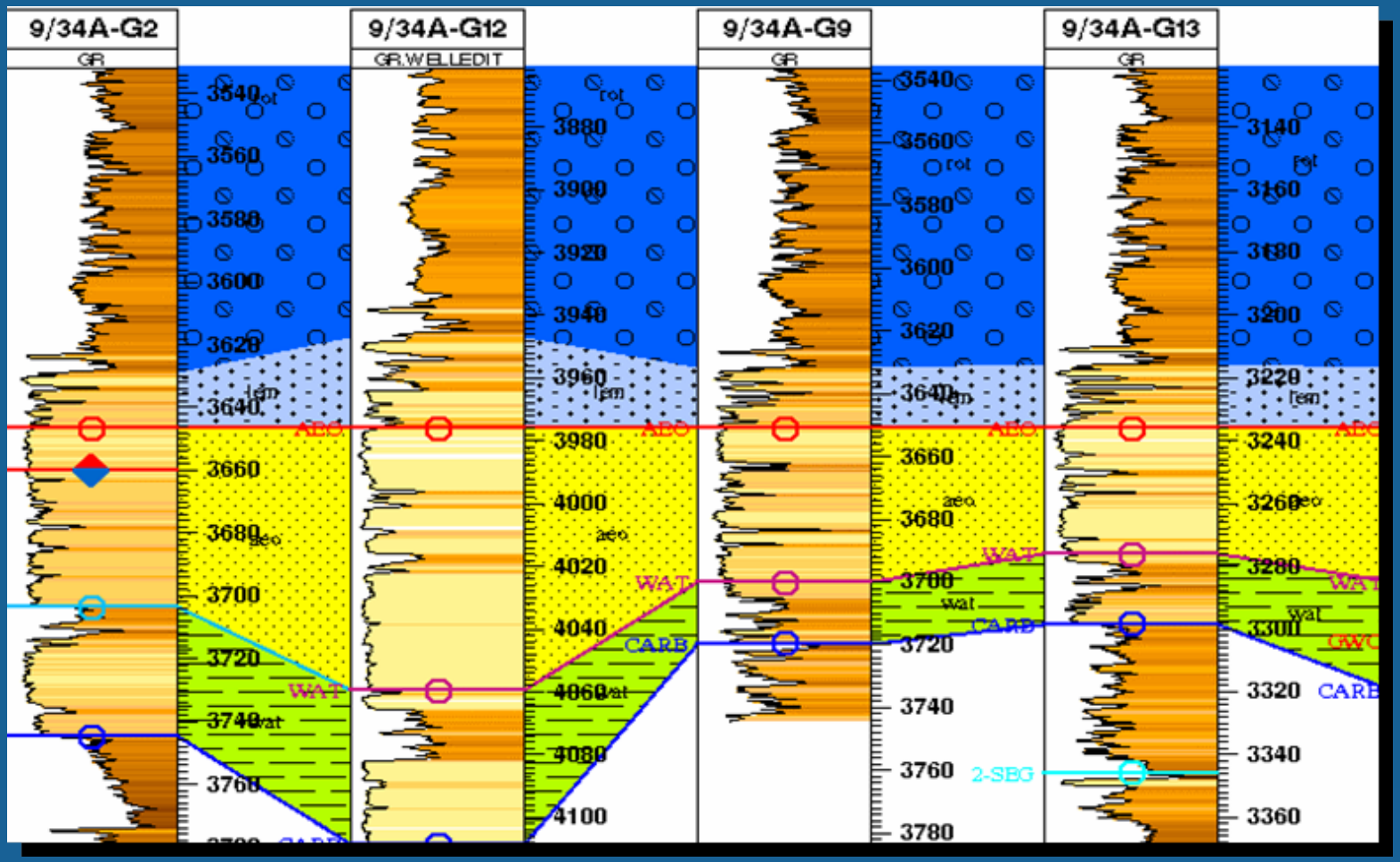
# Well-to-Well Facies Correlation



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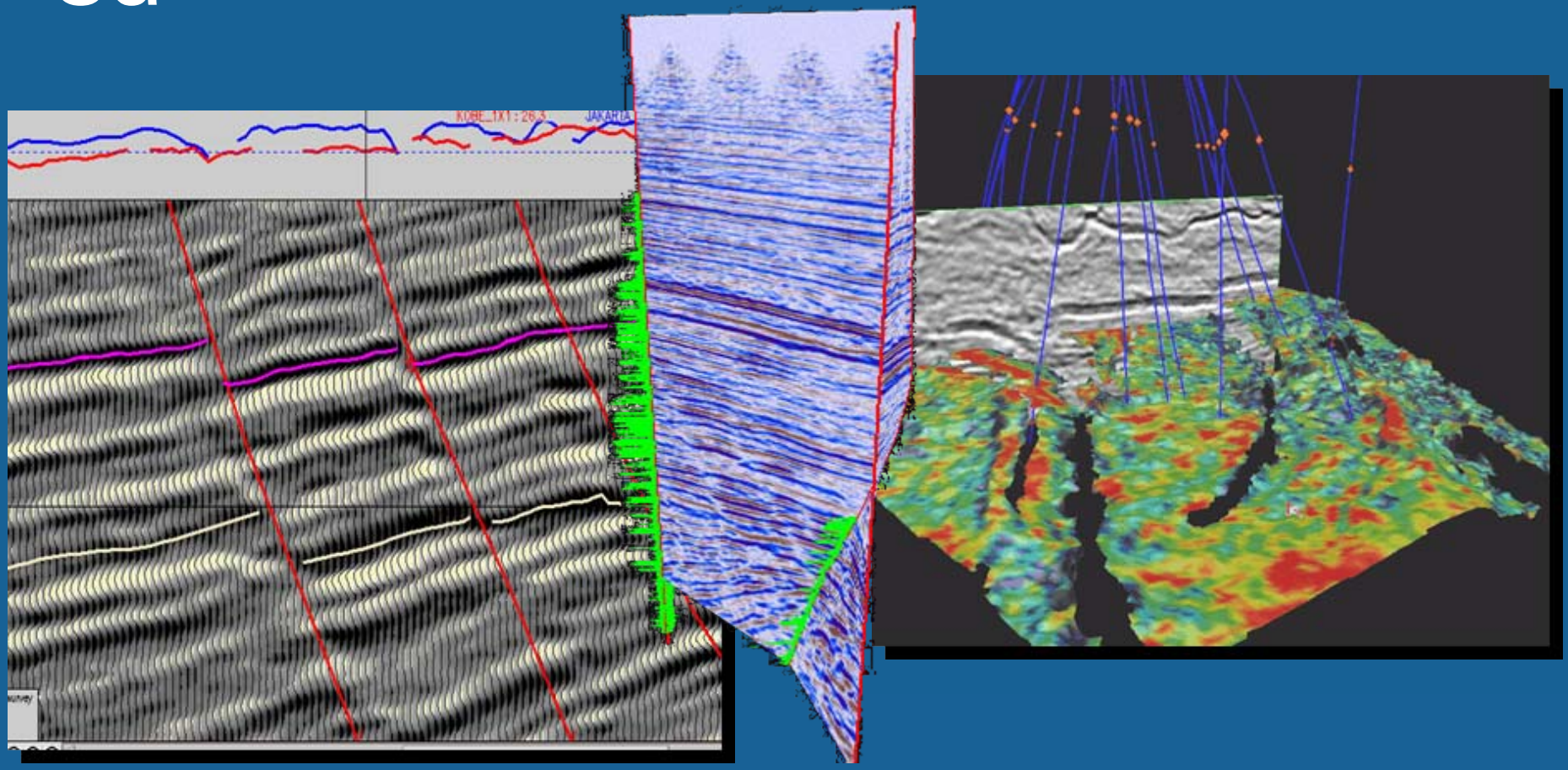
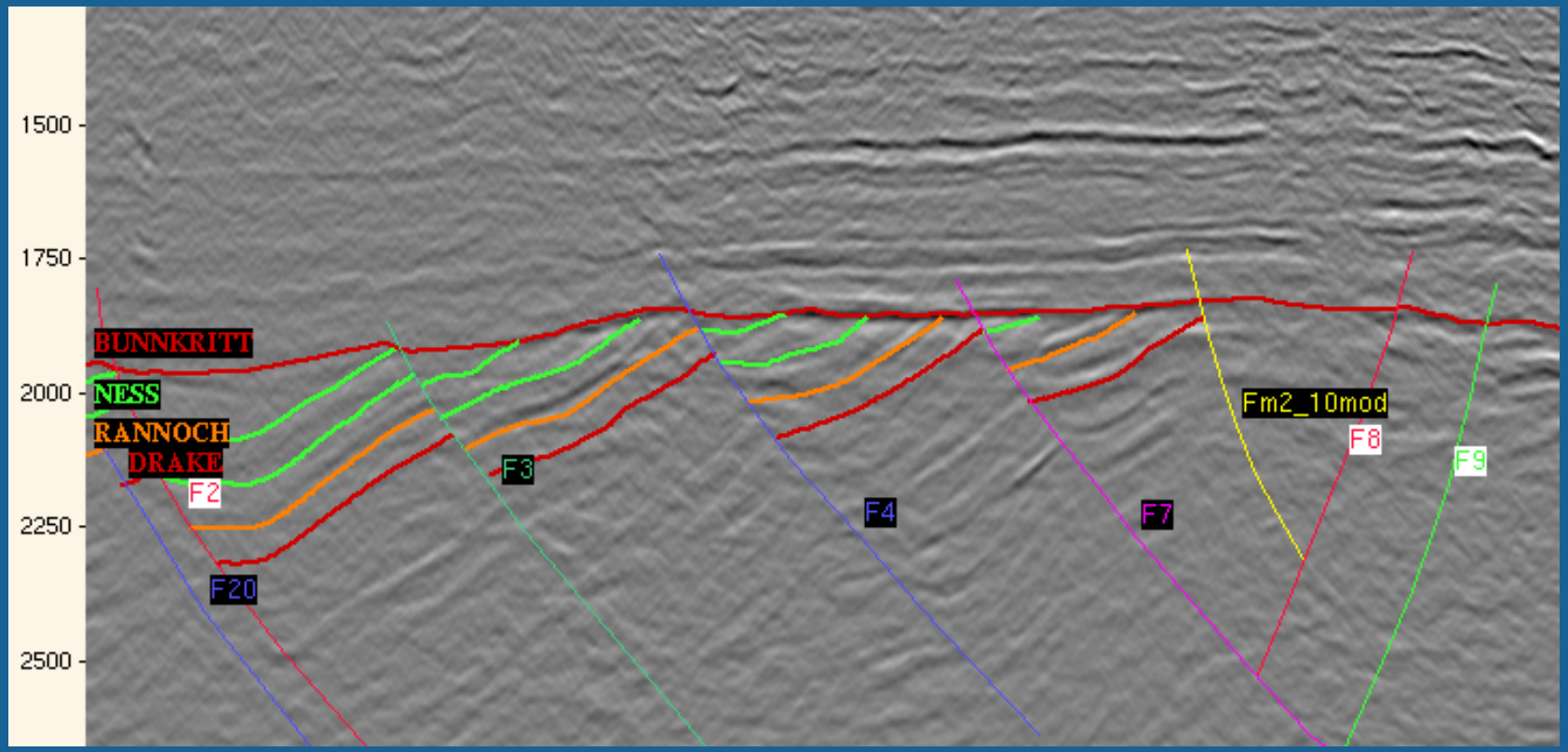
# Seismic Interpretation – 2d and 3d



# Example of Incorporating 3d Seismic for Structural Framework

- Seismic Stratigraphy – interpretations of horizons and faults



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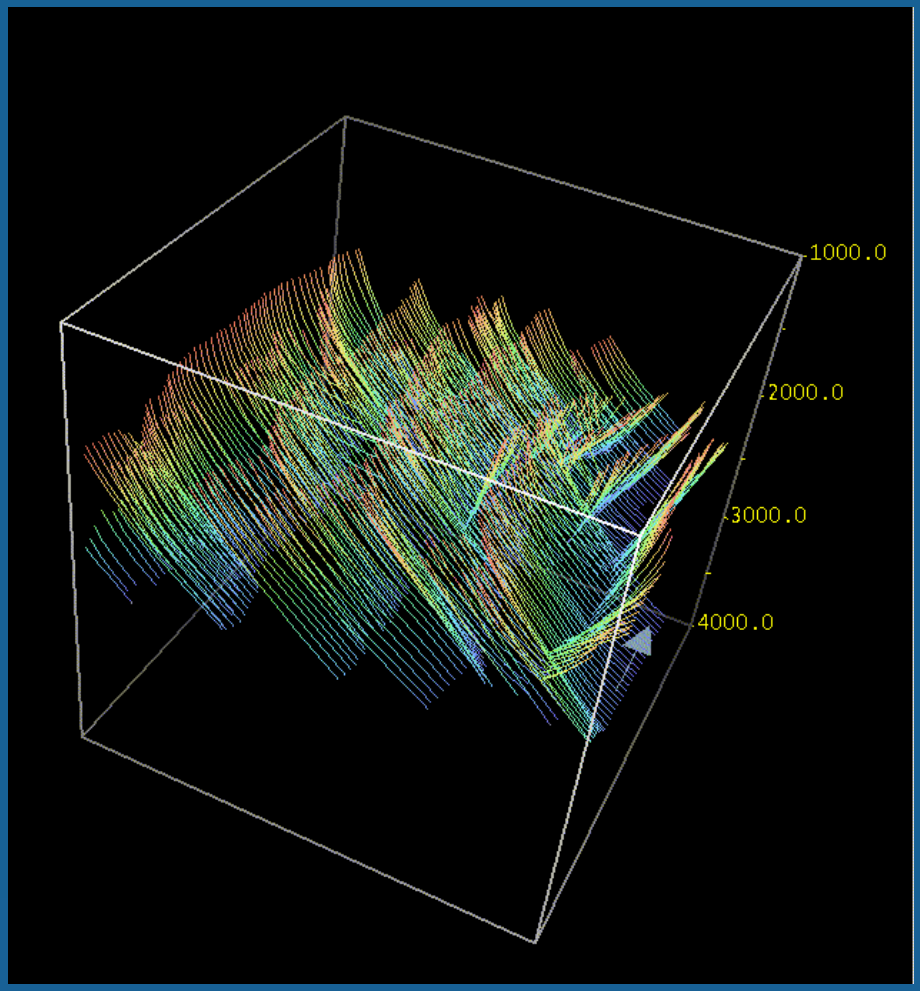
# Seismic Example – Fault Interpretation

- Fault segments interpreted from 2d seismic cross sections of 3d seismic volume



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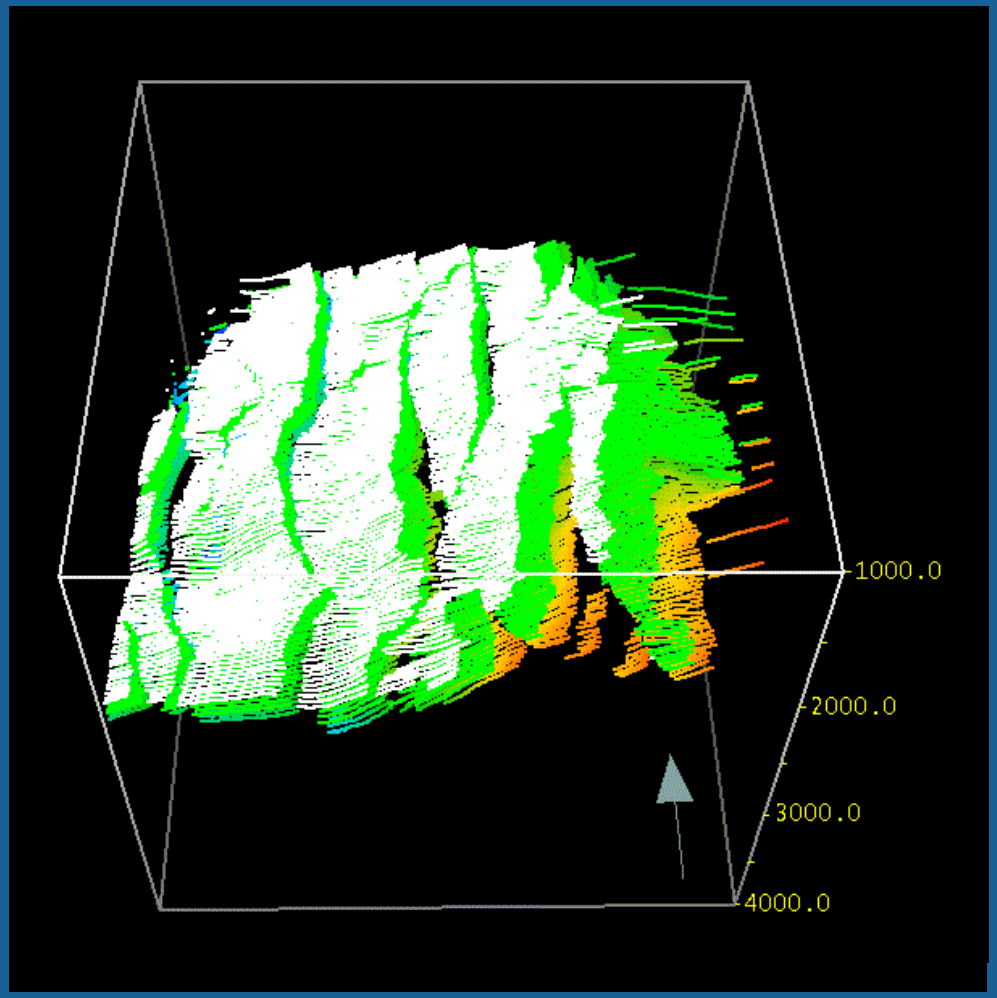
# Seismic Example – Horizon Interpretation

- Unconformity
- Horizons
- Interpreted directly from seismic



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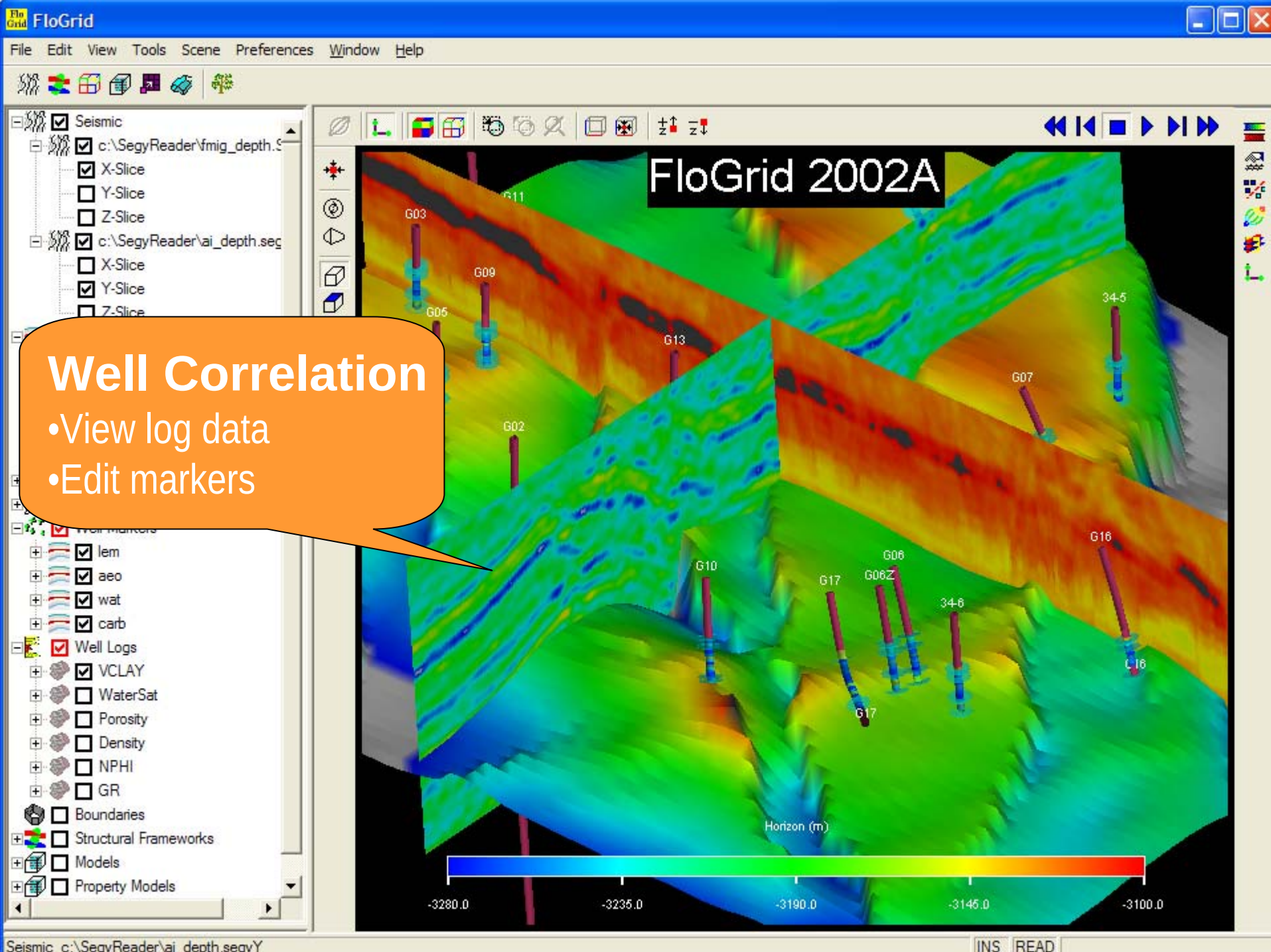
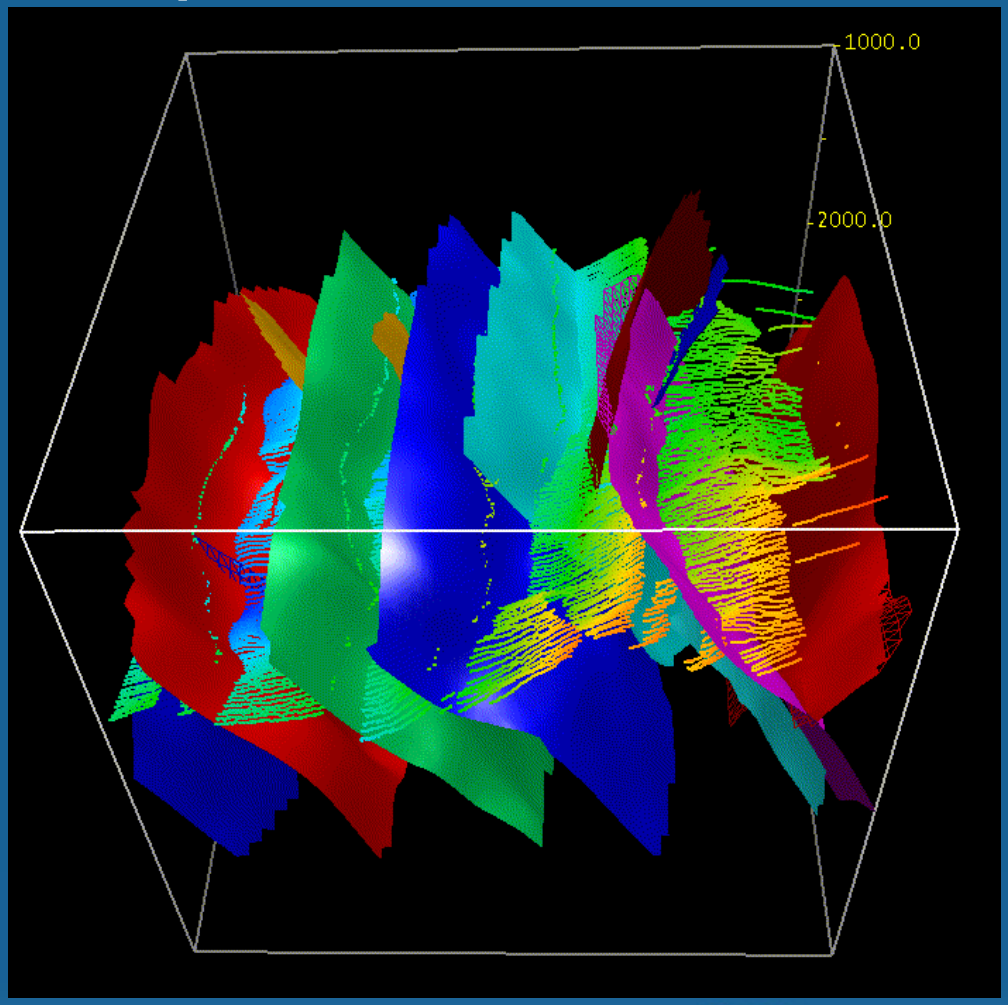



# Well Correlation

- View log data
- Edit markers

# Seismic Example – Fault Framework and Horizon Interpretation

- Horizon interpretation in relation with fault framework



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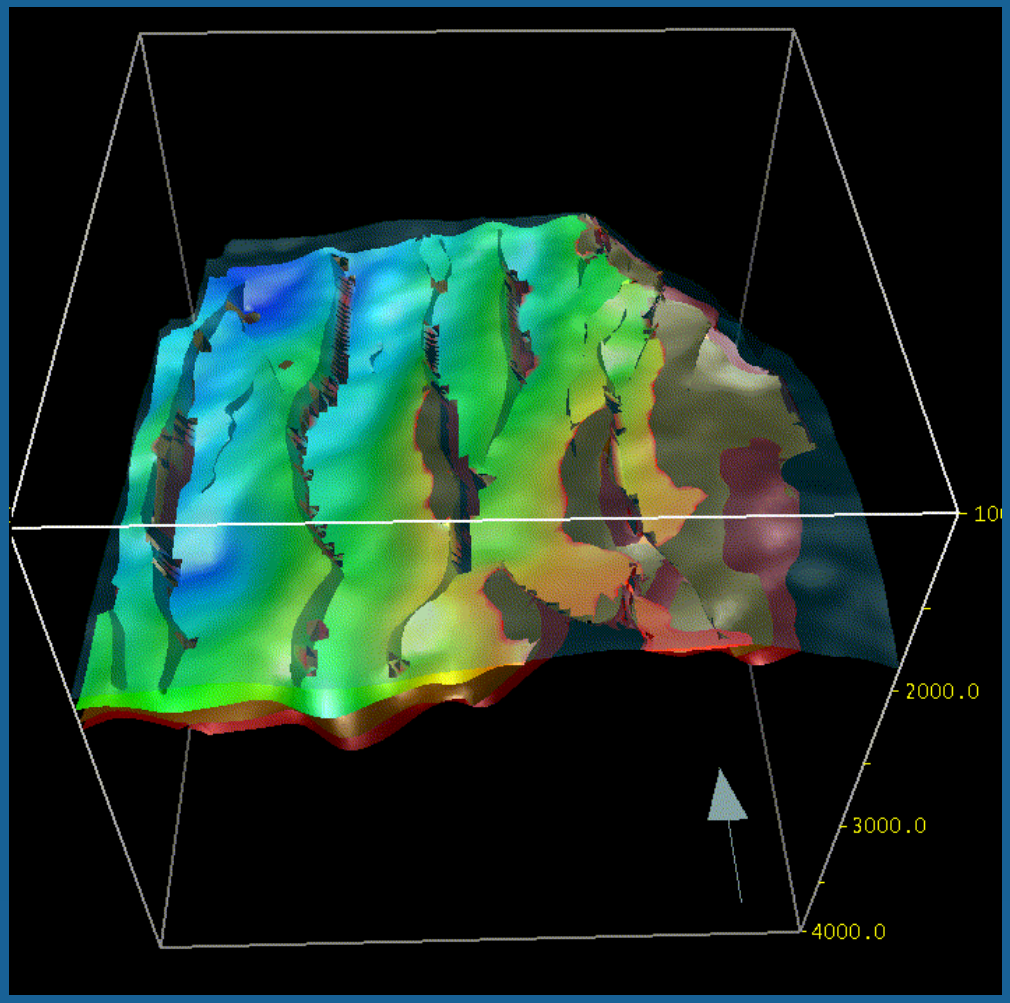
# Seismic Example – Build Structural Framework

- Structural framework is constructed from horizons and unconformities



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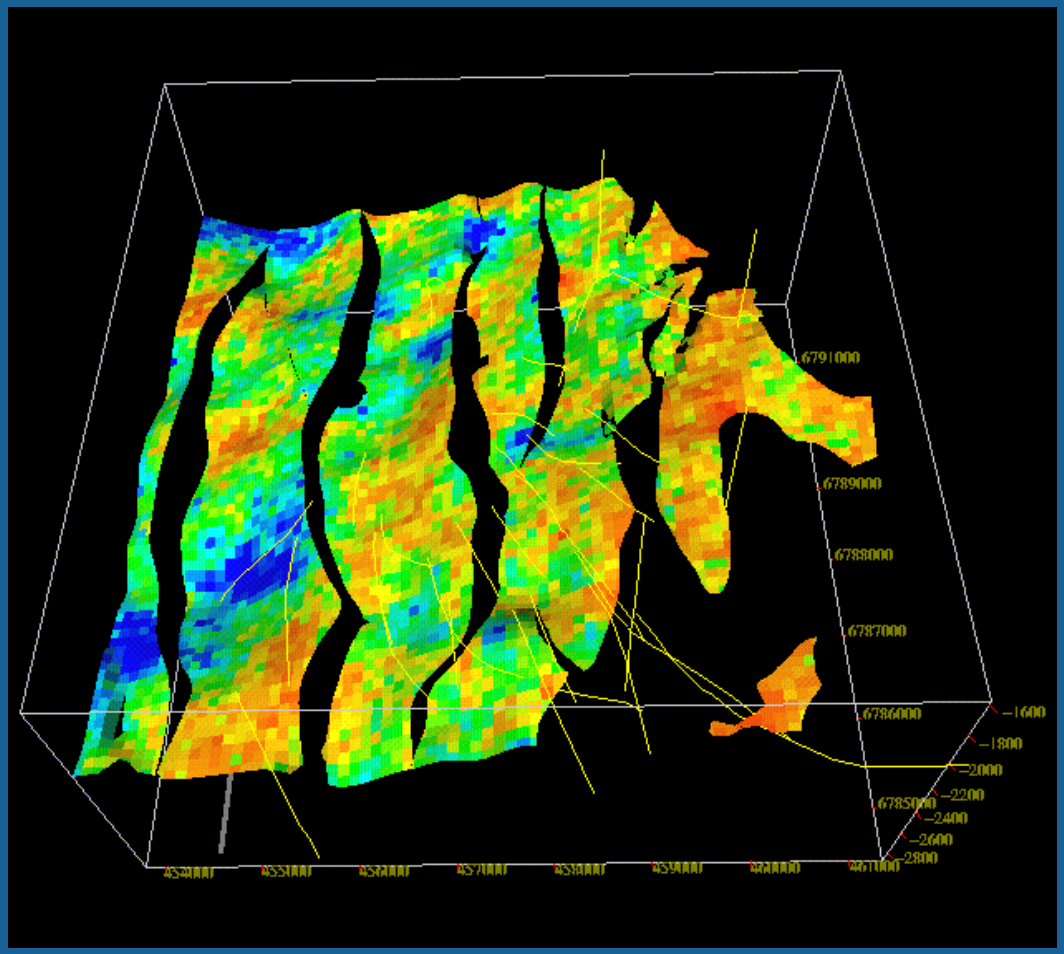
# Property Population: Effective Porosity

- Depth Slice of effective porosity populated using Sequential Gaussian Simulation conditioned on geophysical logs



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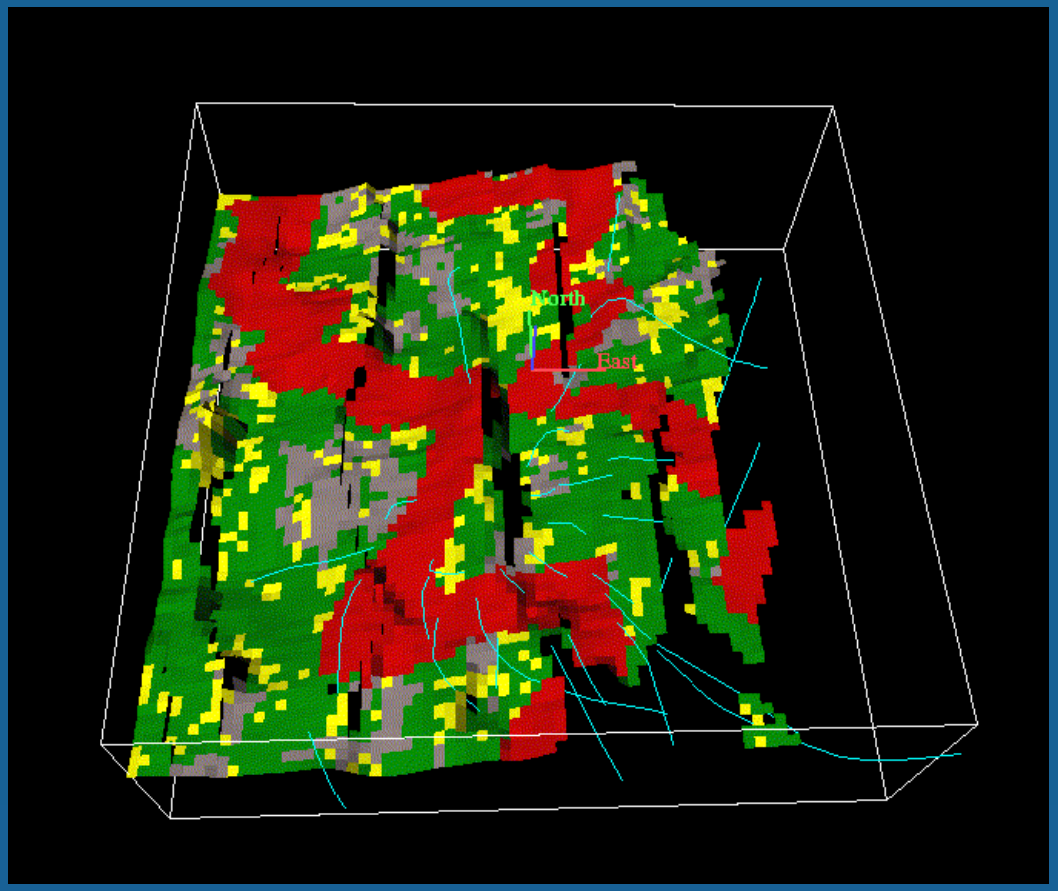
# Property Population: Fluvial Object and Indicator Simulations To Represent Lithology

- Fluvial Object Simulation to model channels – conditioned on well data
- Indicator Simulation to fill in other lithologies – conditioned on well data



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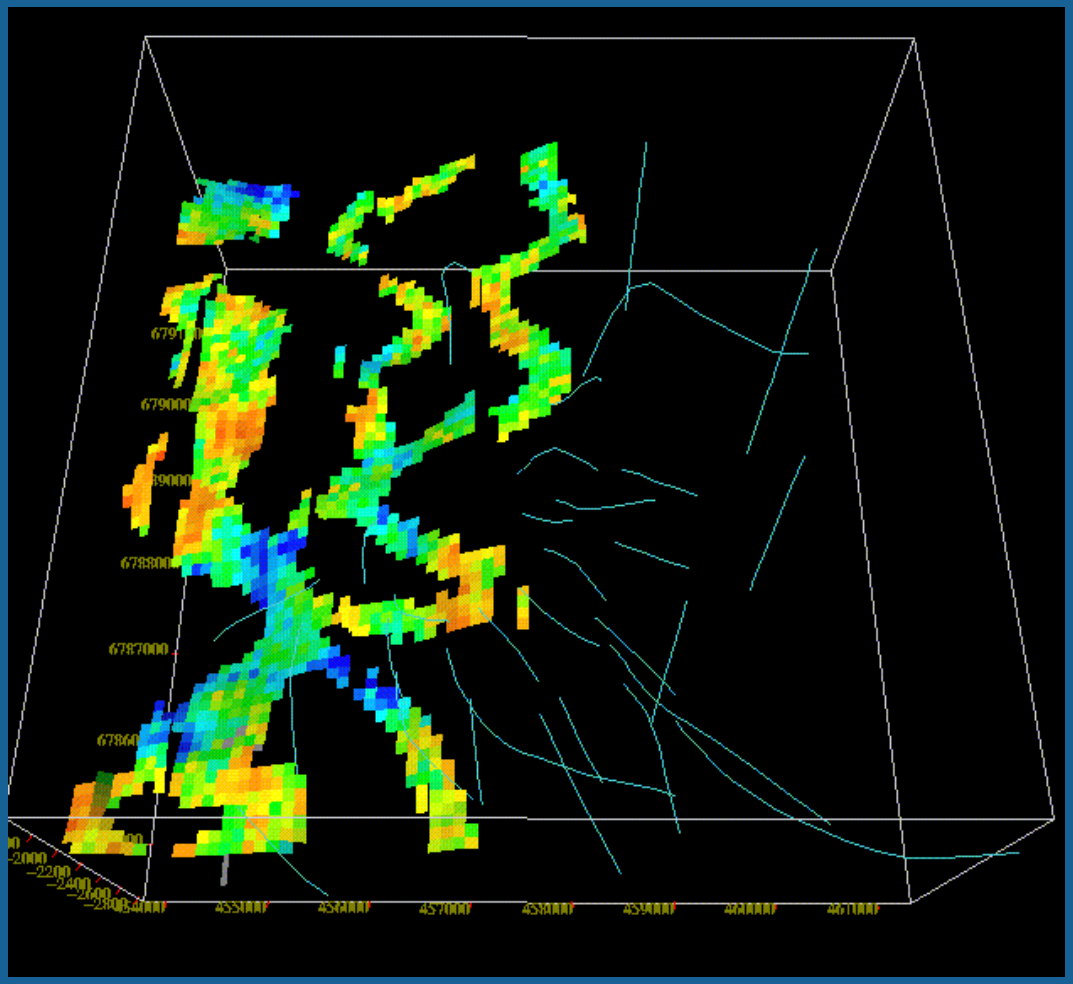
# Selective Population of Property Grid

- Use lithology grid as template to selectively populate effective porosity within channels



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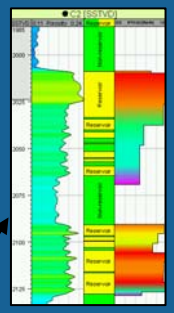
# Property Modeling in Petrel – Overview

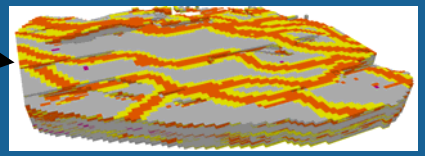
**Property modeling involves a number of steps:**

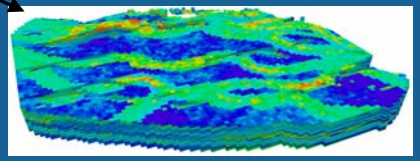
- Upscaling (blocking) of well logs
- Geometrical Modeling
- Facies Modeling
- Petrophysical modeling
- Data Analysis

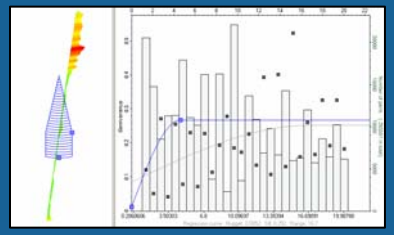
**General tools for working with properties :**

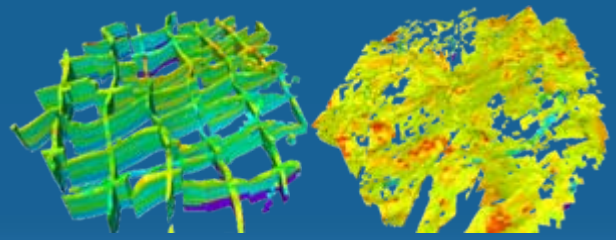
- Property Calculator
- Property Filter
- Property Player

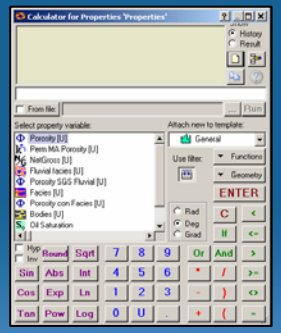













**ERSP Fall PI Meeting**
**October 23–25, 2006 Oak Ridge, TN**

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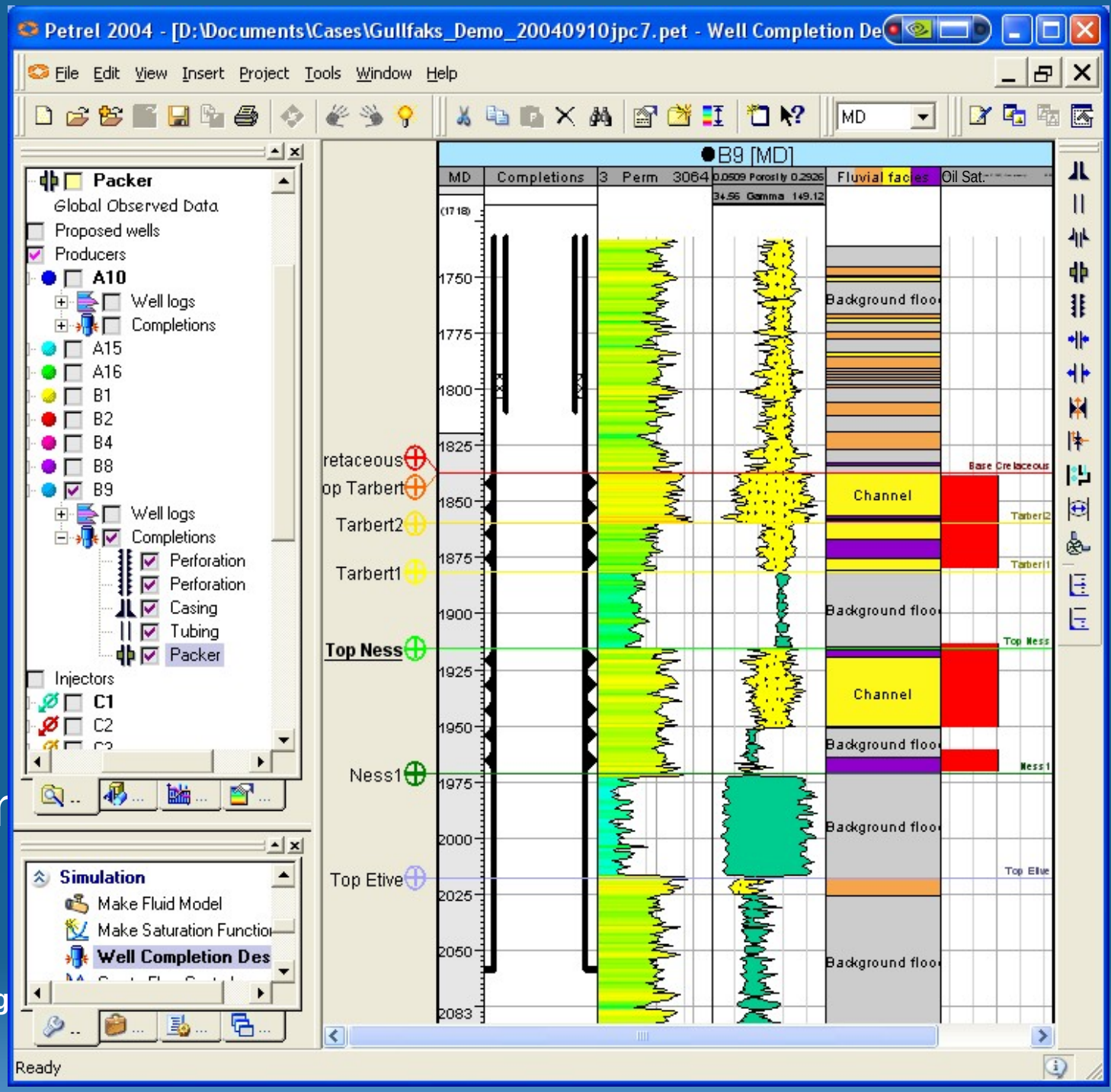
# Petrel Usability : Well Analysis

- Logs
- Picks
- Facies
- Fluids
- Completion



# Upscaling of Well Logs
## Overview

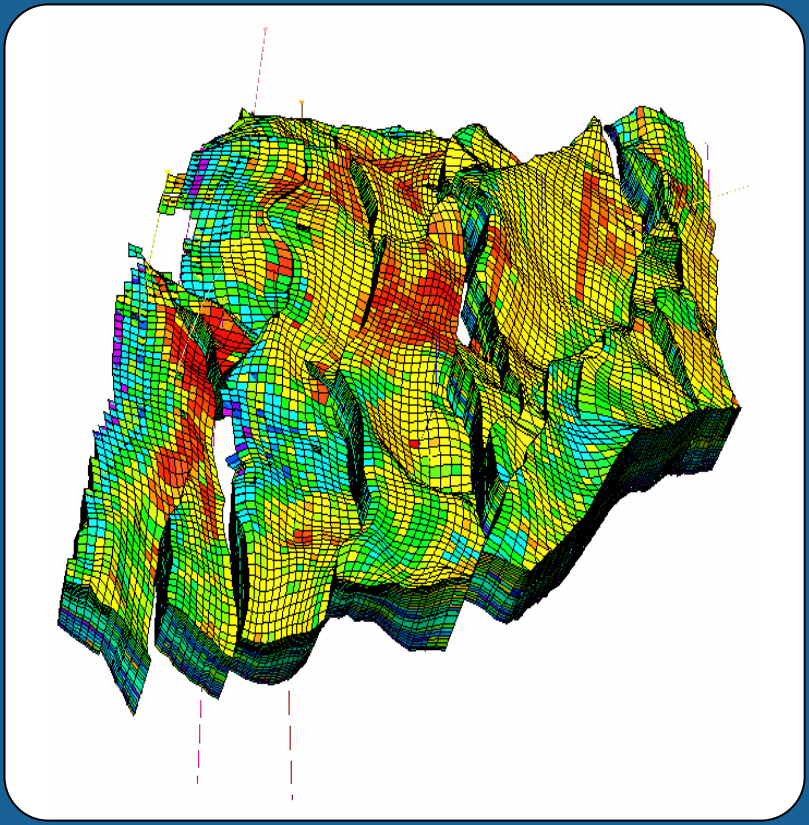
Cells along the well path

↓

Values assigned to cells

↓

Upscaled logs used to populate the 3D grid (along with other data types)



# Upscaling of Properties

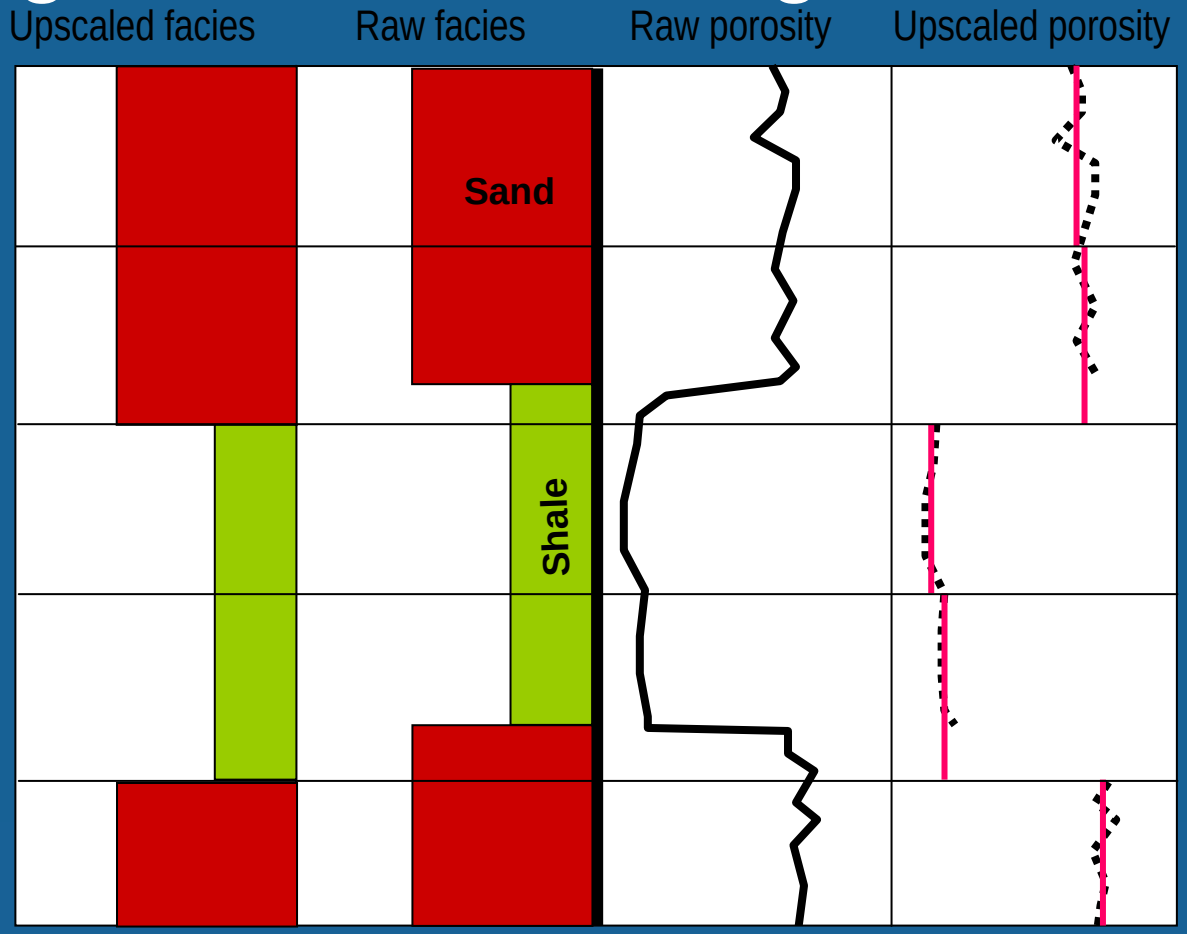
- Property up-scaling can be divided into two main categories:

  1. Averaging
  - The averaging methods can be used for all properties. Choose between various algorithms.
    - Continuous properties – arithmetic, geometric, harmonic, volume weighted arith./geo./har.
    - Discrete properties – “most of”, min, max, arithmetic

  2. Flow based tensor up-scaling
  - The flow based tensor up-scaling can be used for permeability as this property may vary directionally.

# Upscaling of Well Logs

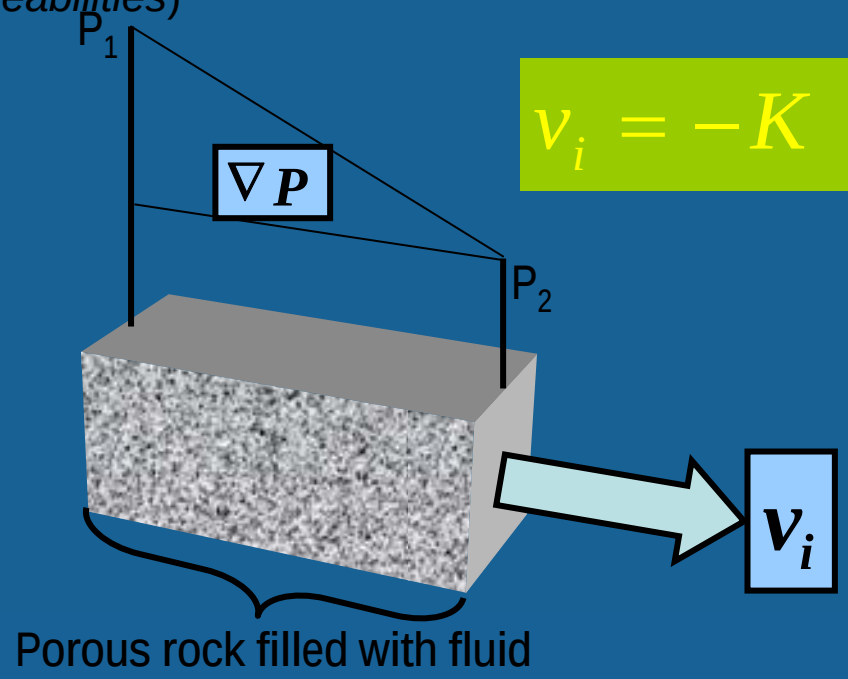
## Biasing to a Discrete Log



# Upscaling of Properties

**What is Flow Based Tensor Up-scaling?**

Uses Darcy's equation and a given pressure gradient on the fine scaled grid cells in the I, J and K directions to calculate the resulting Perm-I Perm-J and Perm-K in the coarse grid (*choose between XYZ or IJK – Full tensor also calculates the resulting diagonal permeabilities*)




$$v_i = -K \ \mu_i^{-1} \nabla P$$

More time (and CPU) consuming than other averaging methods - use *filter* settings!



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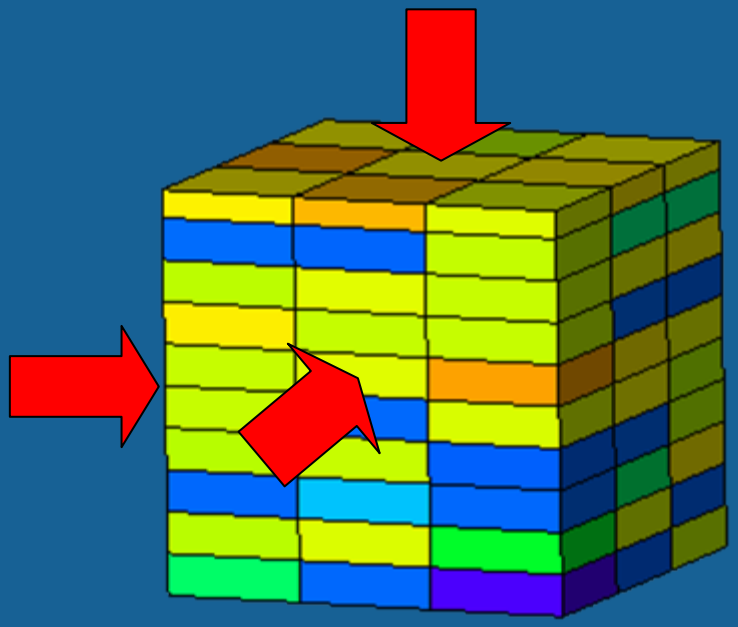
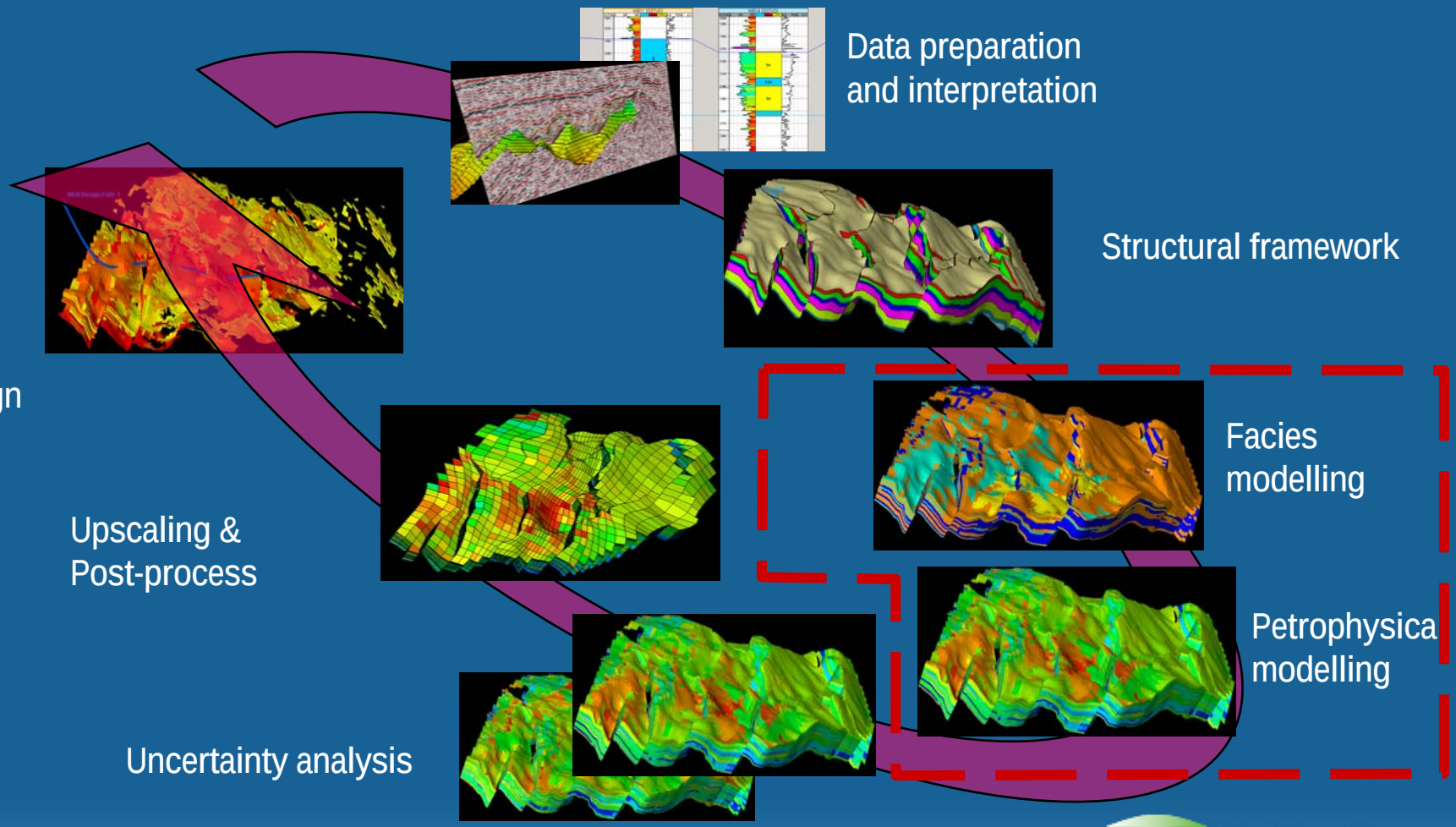
# Upscaling of Properties

## Flow Based Tensor Up-scaling (continued)

- Permeability is very different from other properties since the effective permeability of an area is affected by it's distribution and the orientation in which it is measured
- Designed for Permeability to keep the flow properties of the coarse simulation grid the same as for the fine scaled geological grid
- The average flow velocity in the coarse grid will remain the same as in the fine grid.



# Property Modeling
## Reservoir Modeling Workflow



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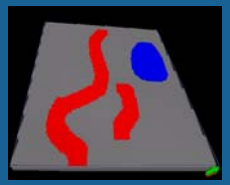
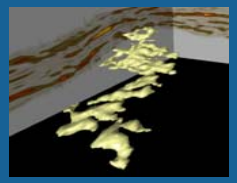
# 3D Property Modeling

## Main Property Modeling Techniques

Facies

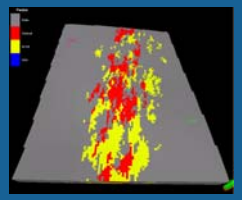
- Deterministic

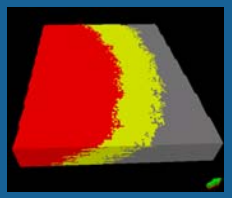




Interactive,
Seismic volume extraction

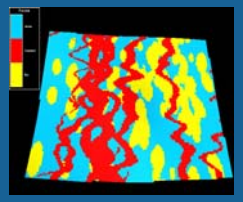
- Stochastic
  - Pixel based

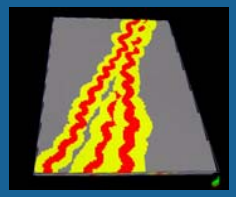




Fuzzy facies or facies transition
SIS, TGSIM

  - Object based

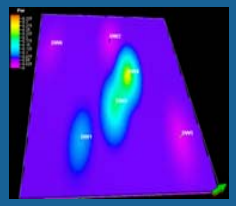




Facies with defined shapes
Object, Fluvial

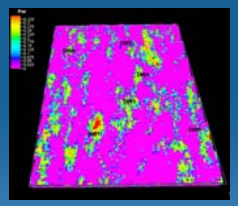
Petrophysical

- Deterministic



Interpolation with smooth effect
Kriging, Moving average

- Stochastic



Regenerate local variation
SGS



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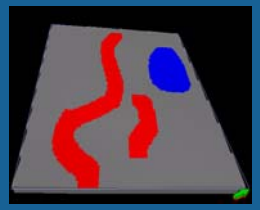
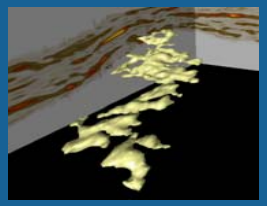
# Facies Modeling – Overview

- If well logs are up-scaled, they can be used in Deterministic and Stochastic modeling
- If no logs are available, deterministic methods cannot be used, only un-conditional stochastic methods and interactive drawing.

FACIES

Deterministic

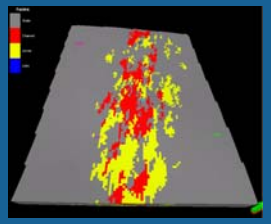


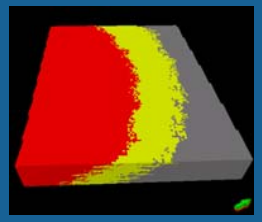


Interactive drawing,
Seismic volume extraction
Indicator kriging

Stochastic

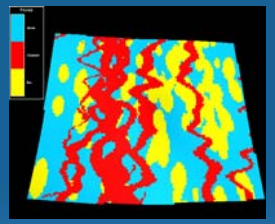
Pixel based

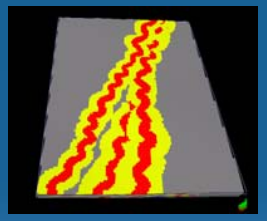




Indicator Simulation
(fuzzy facies – SIS or
facies transition- TGSIM)

Object based





Facies with defined
shapes
Object, Fluvial



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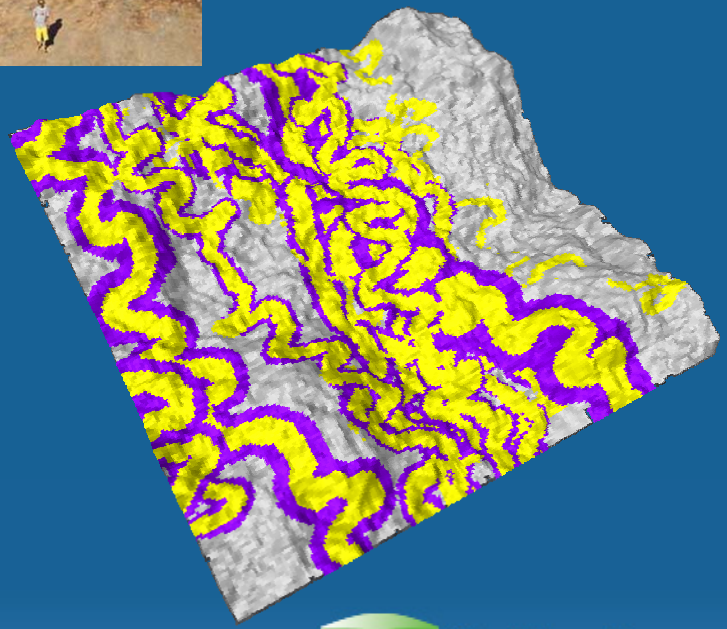
# From deposition to reservoirs





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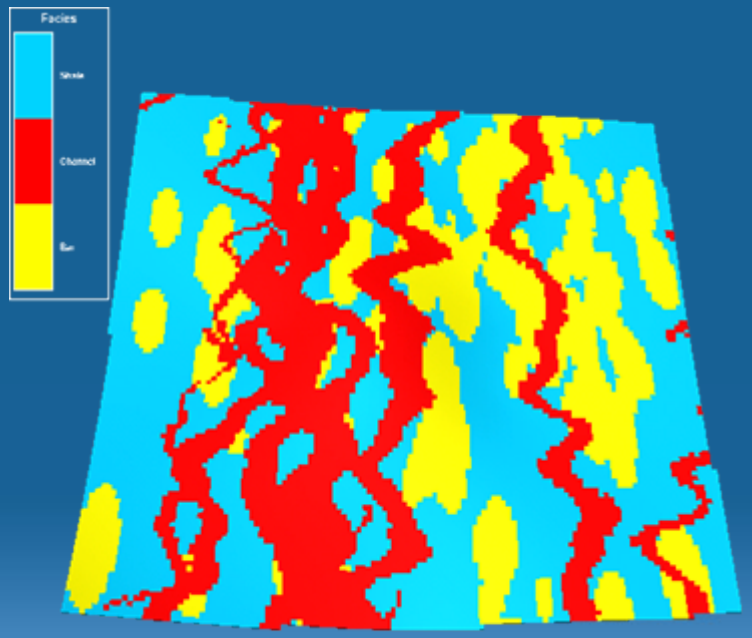
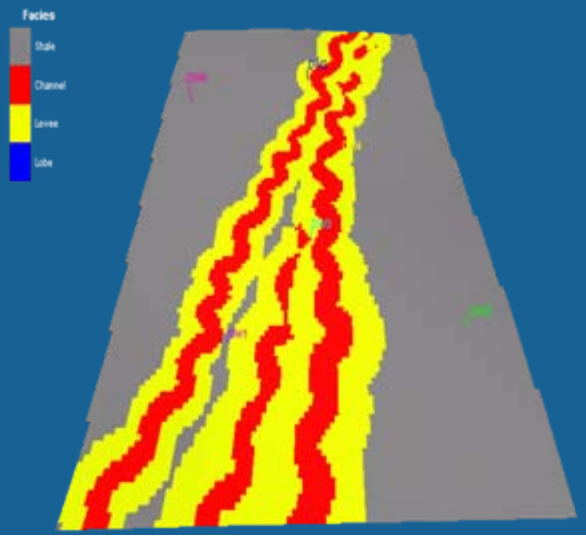
# Object Facies Modeling

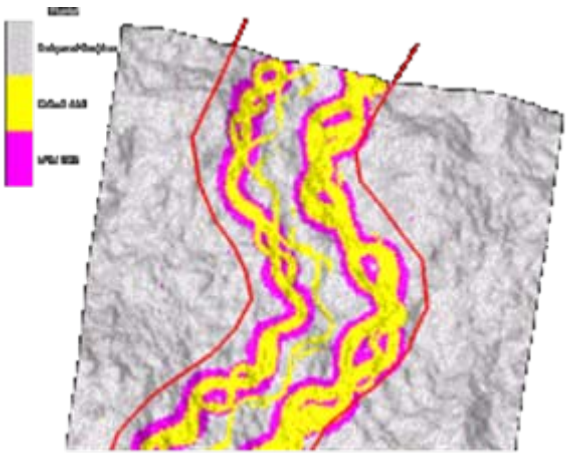
- Realistically capture facies architecture and geometry
- Object based with various predefined shapes
- Channel and isolated objects fully integrated
- Modeling rules
- Vertical and lateral trends
- Multiple realizations

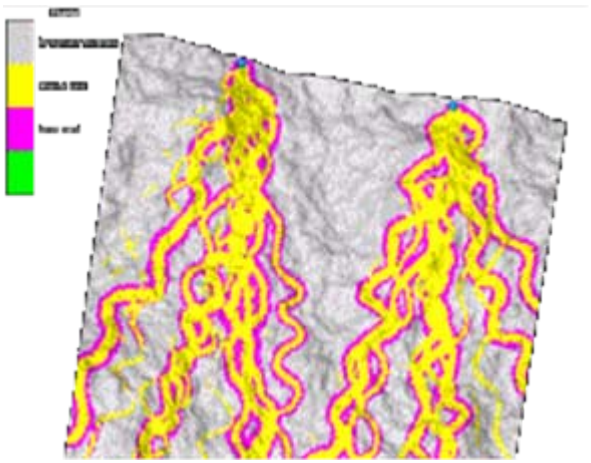


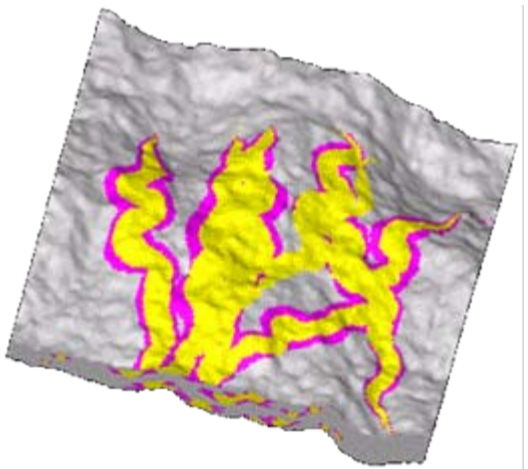
# Facies Object Modeling – Fluvial Channels

- Channel, levee association
- Vertical and lateral trends
- Flow-lines and source points
- Flexible shapes
- For fluvial, deep water and other
- Channelized facies



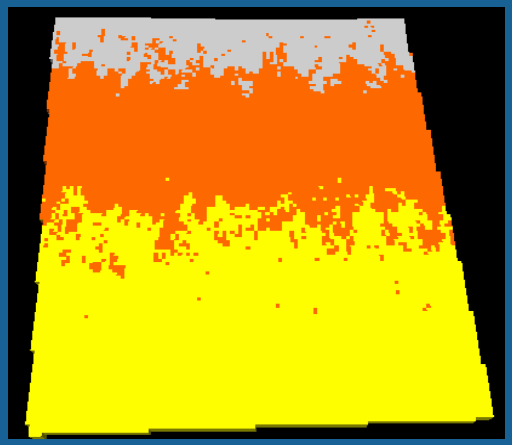


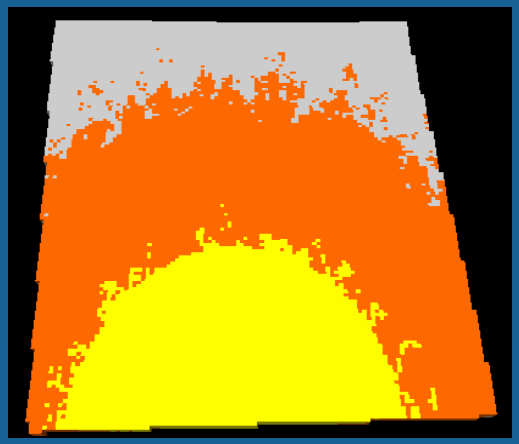


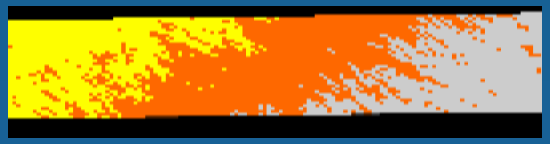
# Facies Transition Simulation

## Truncated Gaussian Simulation Algorithm

- Pixel based approach used to model ordered facies transiti
  - Facies boundary type can be linear or curved
  - Interactive interface for facies boundary editing
  - Interfingering effect at facies boundaries
  - Clinoform for facies interfingering









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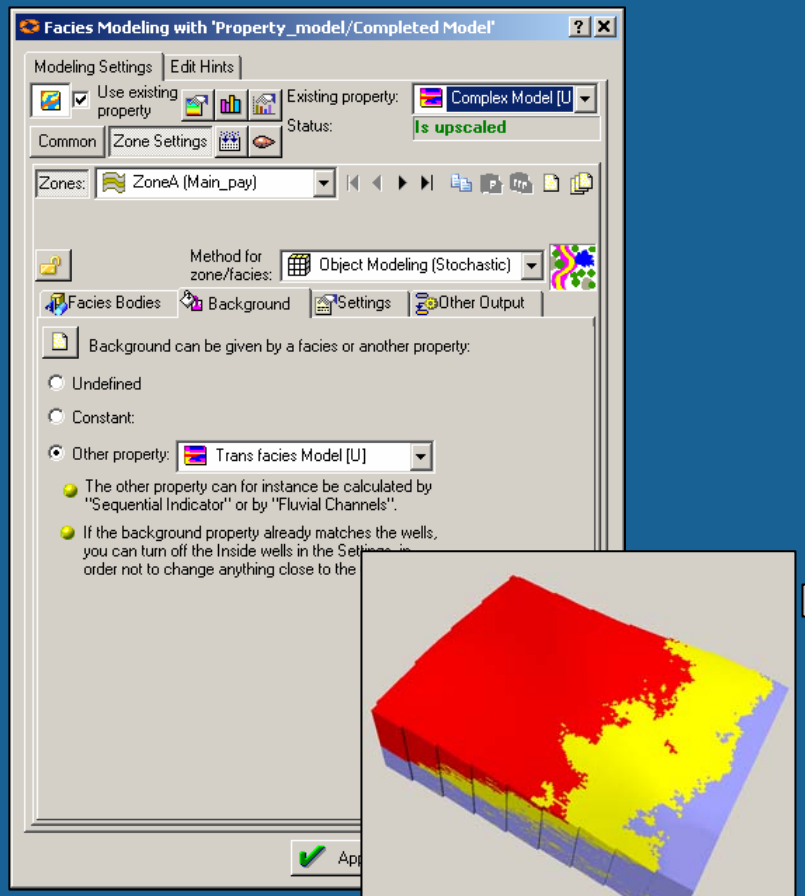
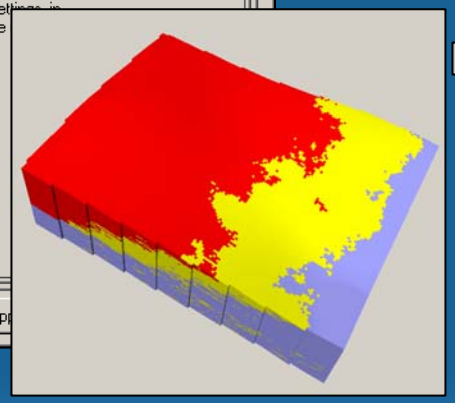
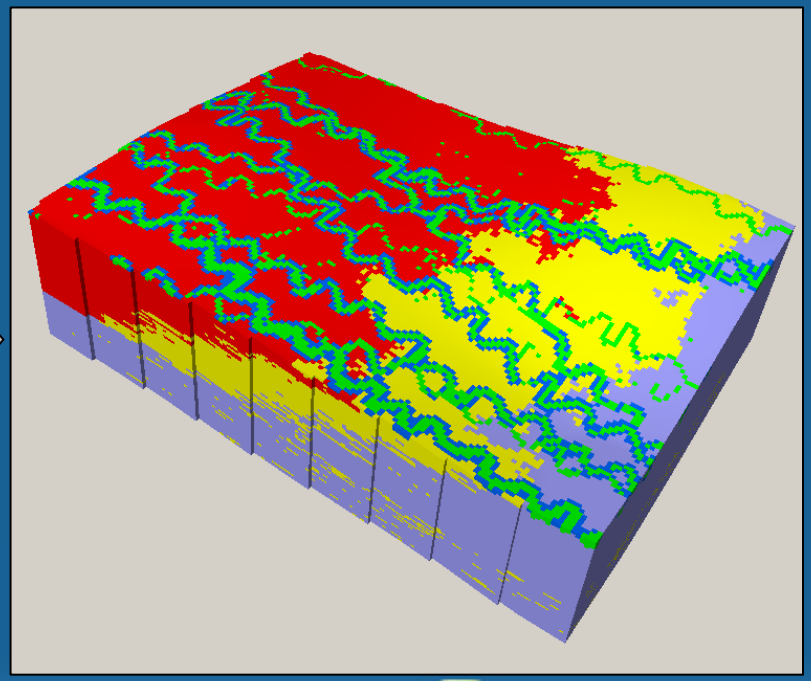
# Facies Transition Simulation

## Complex Property – Result







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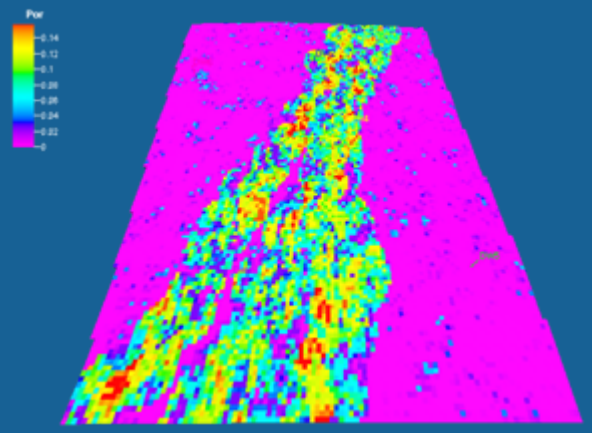
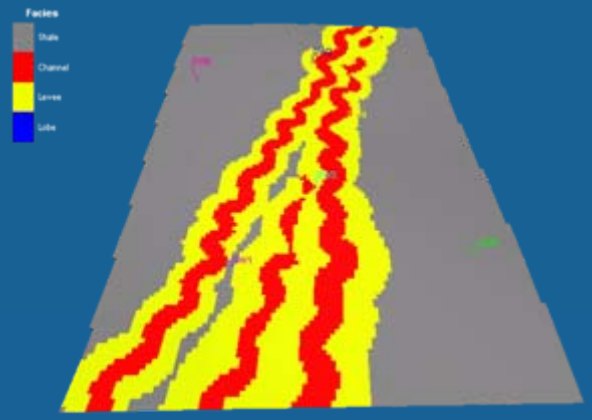
# Petrophysical Modeling
## Stochastic Modeling

- Sequential Gaussian Simulation (SGS)
- Condition to well data & facies model
- Condition to trends & secondary variable
- Choice of variogram models
- Multiple realizations







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# Petrophysical Modeling Using Secondary Information (e.g., Surface Geophysics)

- Methods available in Petrel:
  - Local Varying Mean
  - Co-kriging
  - Usage of Trend
  - Bi-variate distribution

# Collocated Co-kriging Characteristics

- A more simplified equation system → faster than traditional Co-kriging
- No instability caused by highly redundant secondary variable
- Control parameters: secondary variable, correlation coefficient and variance reduction factor
- Only the variogram of the primary variable must be modeled

# Secondary Attribute Example

- Problem:
  - Primary attribute not densely sampled
- Solution:
  - Check whether seismic acoustic impedance cube correlates with primary attribute.
  - Extract the Variogram model parameters from secondary attribute
  - Use secondary attribute in collocated co-simulation



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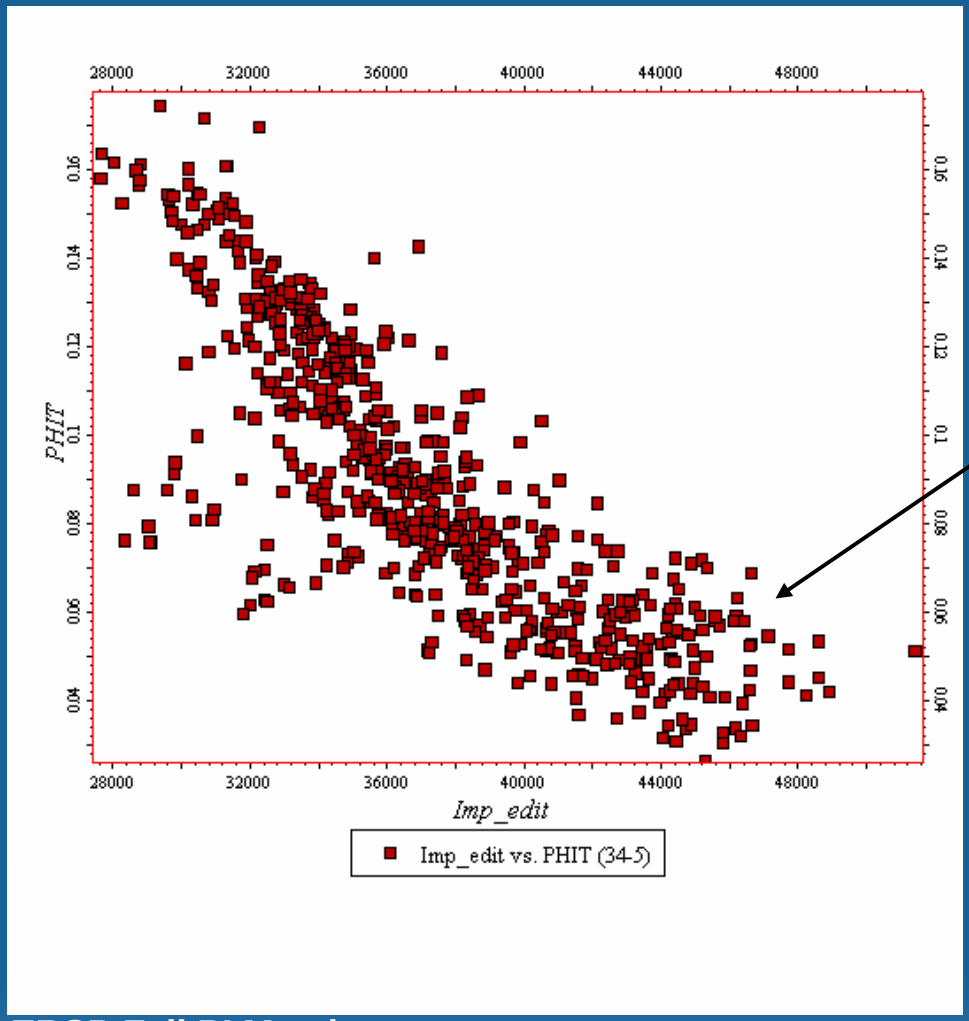
# Secondary Attribute Cross Plot Impedance Log – Porosity Log




## Note:

For low porosity values the impedance is less sensitive.



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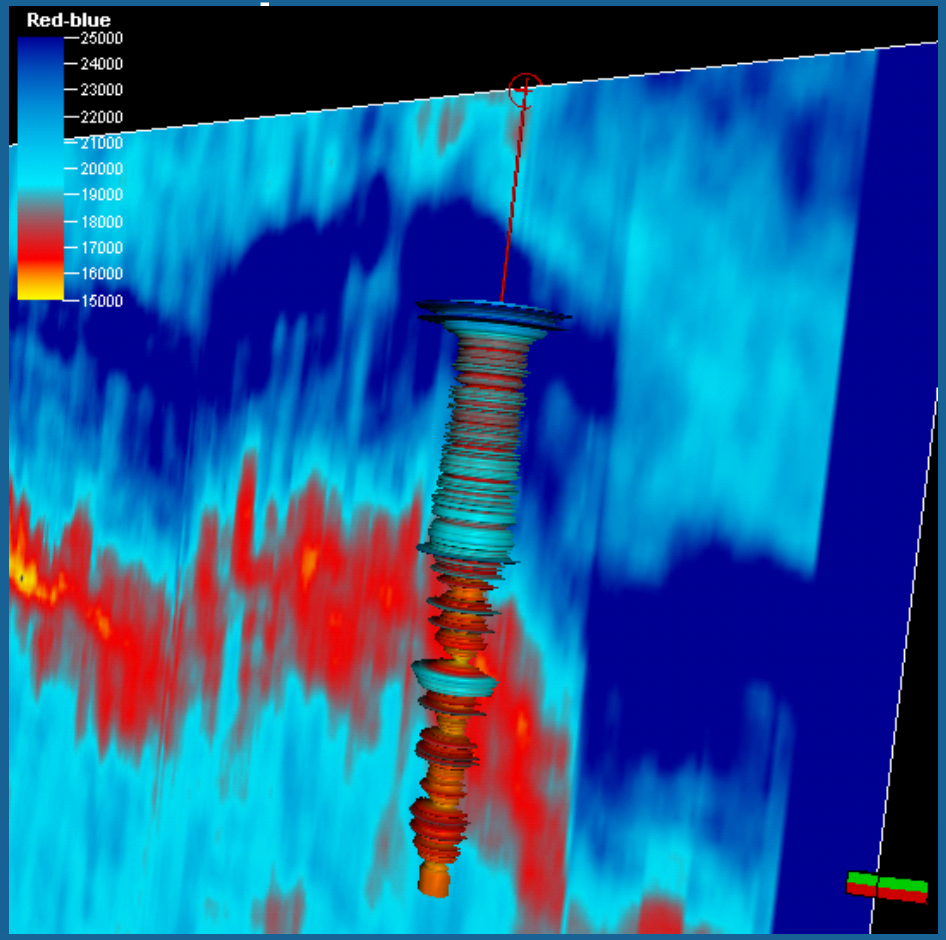
# Secondary Attribute
# Resolution of Seismic Acoustic




**Resolution of seismic AI:**

In the range of 15-30m.

**Resolution of impedance log data:**

1m and less



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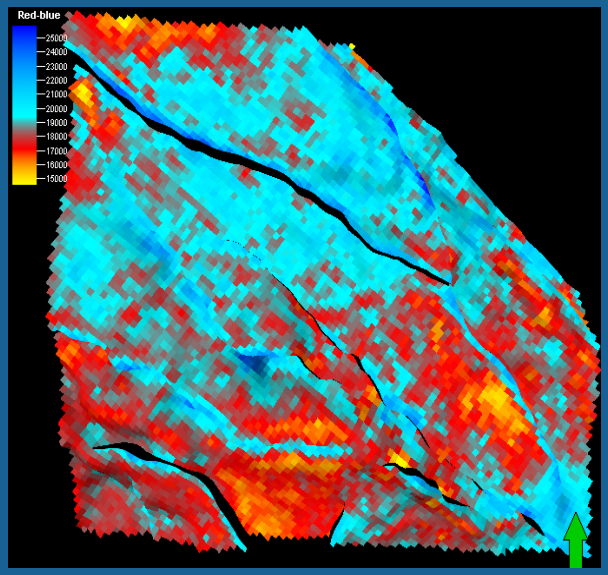
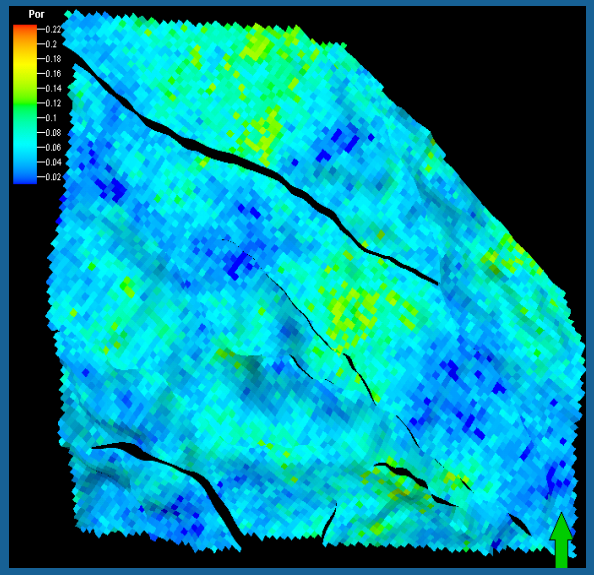
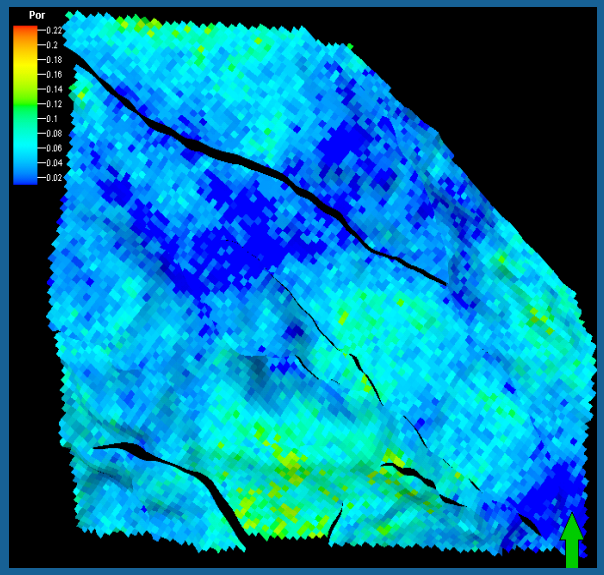
# Porosity Modeling
## Seismic AI as Secondary Input




Seismic Acoustic Impedance

Porosity

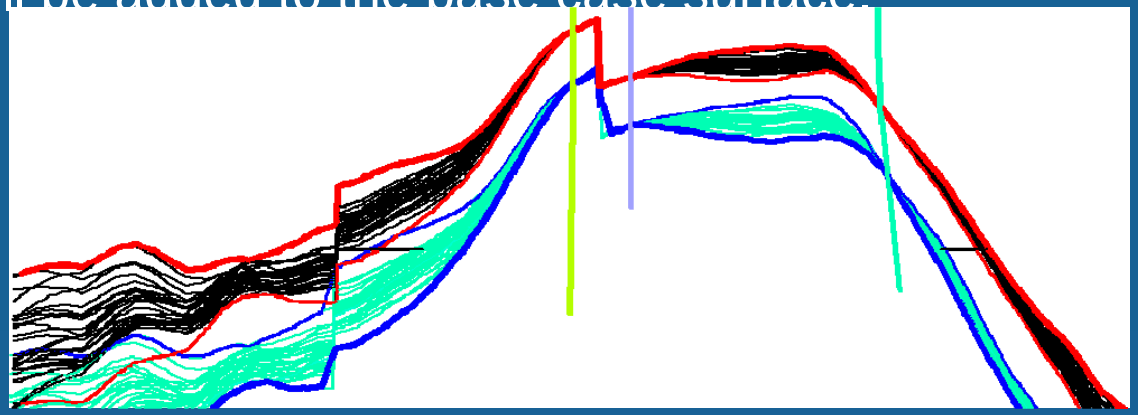
No secondary Attribute

Porosity

Collocated cokriging
Correlation: -0.54

# Structural Uncertainty – Petrel Capabilities

- Assessing uncertainty in pore volume or reservoir performance predictions requires adding uncertainty to the gridded surface elevations
- Some characteristics of the uncertainty:
  - Essentially zero at the well locations
  - Varies smoothly away from the wells
  - Variance depends on the quality of the seismic and the distance from the wells.
- Petrel uses a methodology for creating stochastic error surfaces that will be added to the base case surface.

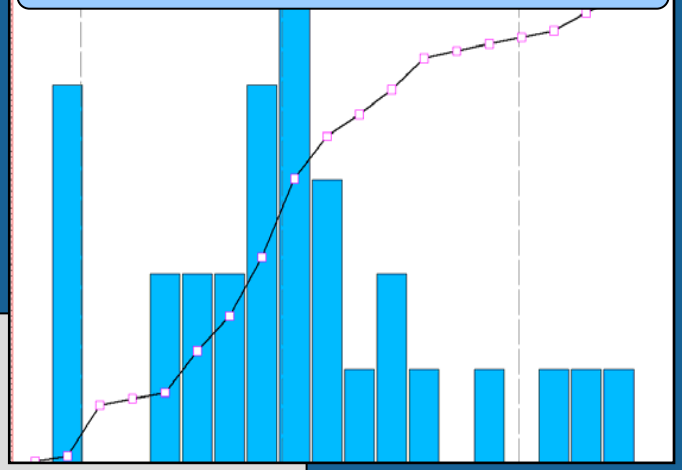


# Structural Uncertainty Analysis

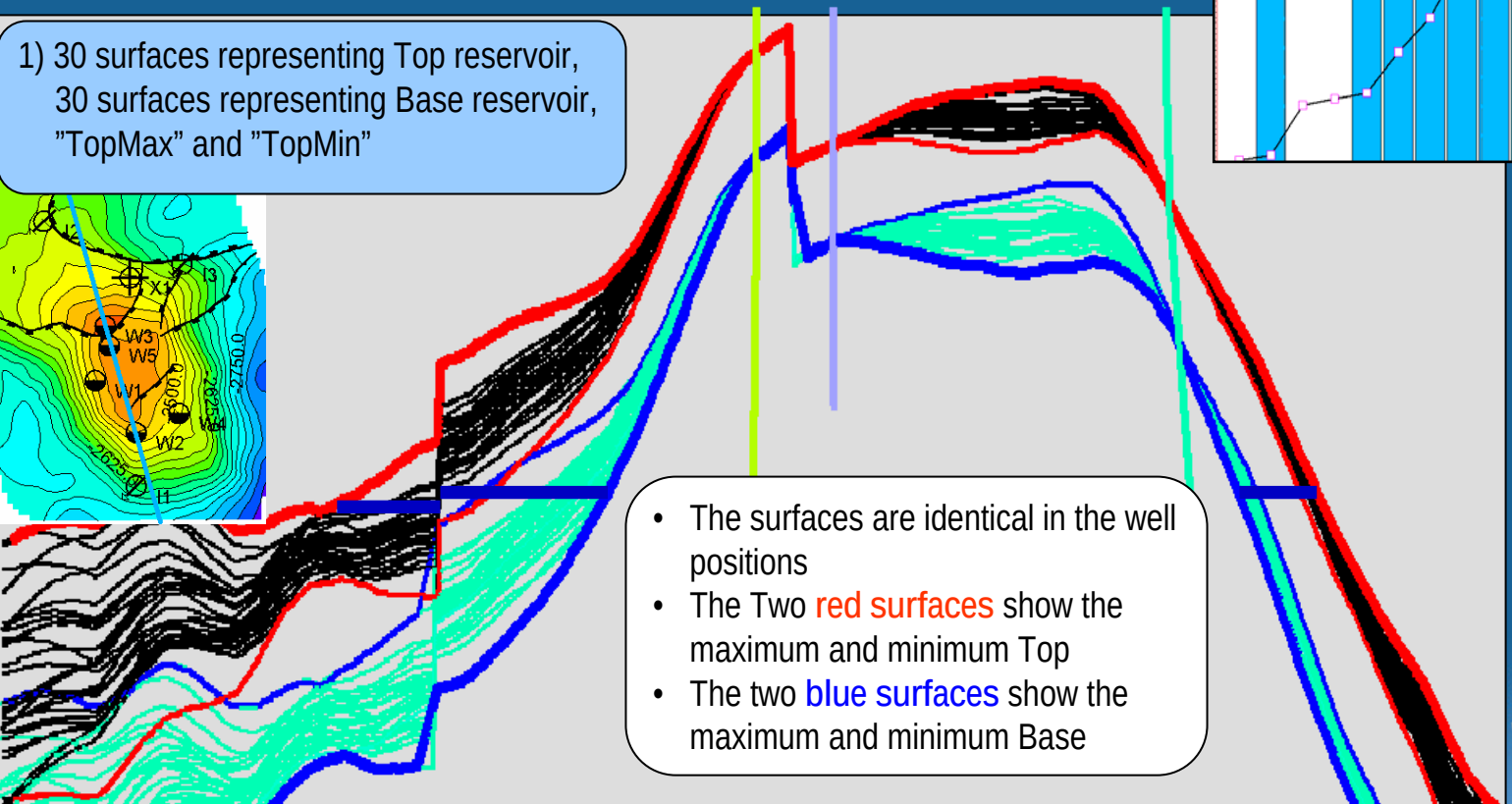
## Results after 30 realizations

For each case different velocities and isochores were used to create the Top and Base reservoir

2) Volumetric results for all the 30 cases.



1) 30 surfaces representing Top reservoir, 30 surfaces representing Base reservoir, "TopMax" and "TopMin"




- The surfaces are identical in the well positions
- The Two red surfaces show the maximum and minimum Top
- The two blue surfaces show the maximum and minimum Base

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# Presentation Outline

- Overview of Reservoir Modeling Workflow
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  - Multi-well analysis
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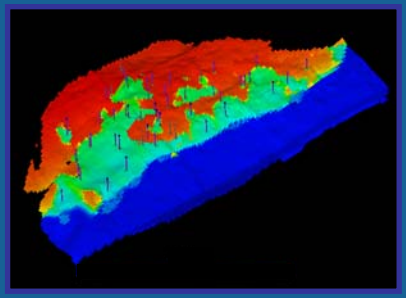
  - Property modeling – (1) facies, (2) petrophysical
  - Uncertainty
- Reservoir Simulation Modeling
  - Grid generation and property upscaling
  - Simulation engines
  - Uncertainty and optimization
- Closing Remarks – application to subsurface water resources

# What is Reservoir Simulation ?

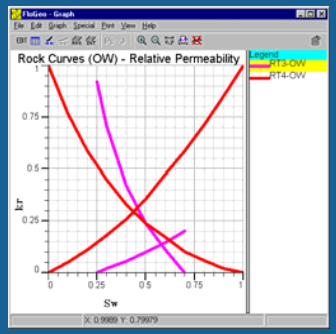


**Reservoir grid model**

→

***geometry, properties***

**Calculate pore volumes, transmissibilities, depths, non-neighbour connections**

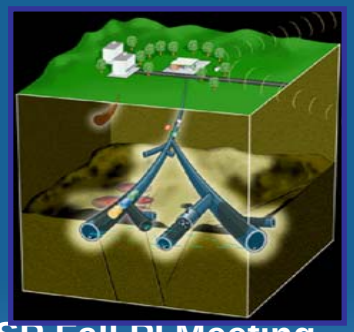



**Fluid description**

→

***composition, flow behaviour, initial conditions***

**Initialize saturations, pressures, fluids-in-place**



**Wells and production system**

→

***locations, completions, production and injection rates***

**Define well model and surface facilities, advance through time and calculate flows and pressures**



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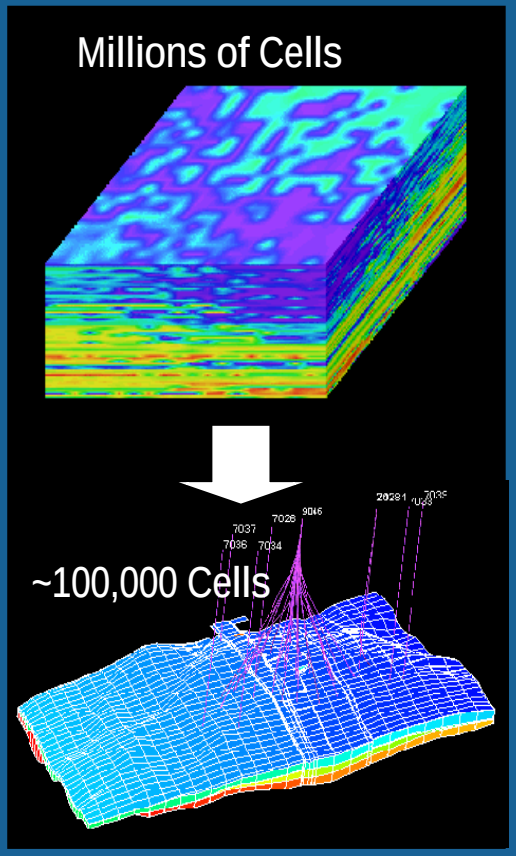
# Gridding for Simulation

- Grid requirements:
  - Adequate description of reservoir structure and initial properties
  - Sufficient detail to describe change in saturation and pressure with time
  - Compatibility with mathematical model

May conflict!

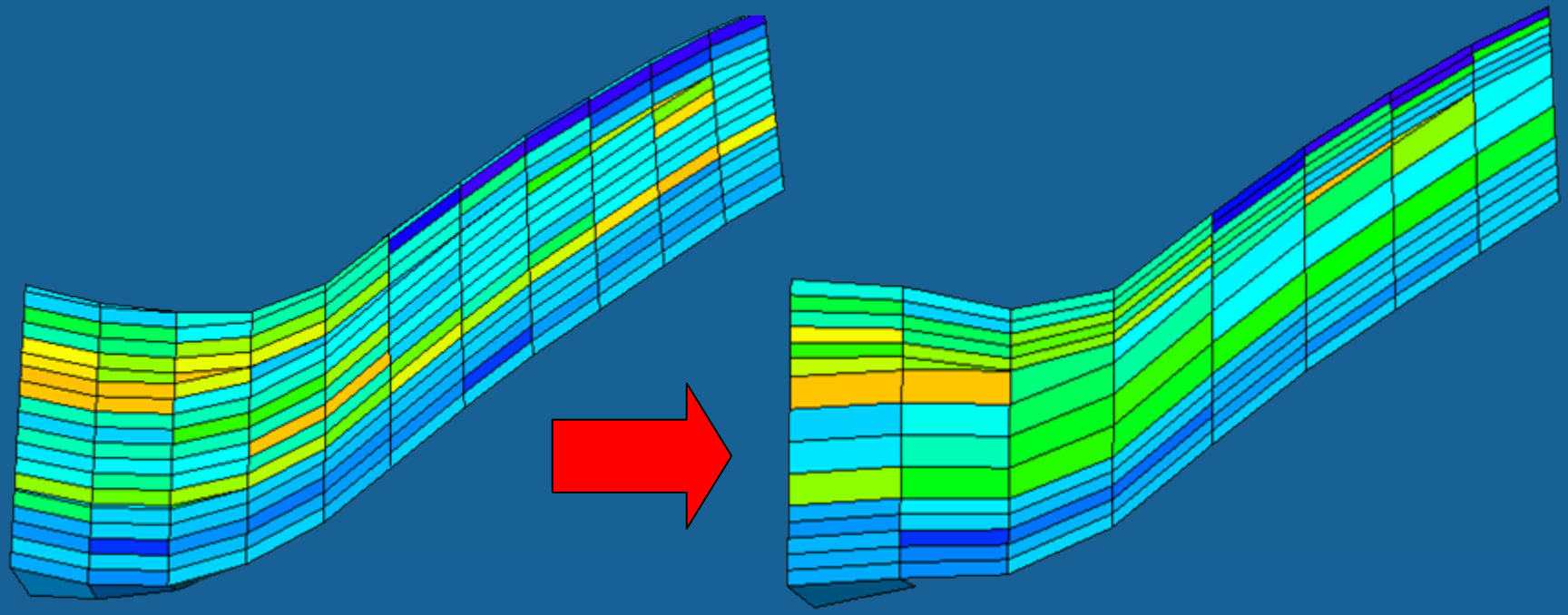
- Simulation grid sizes are limited by time & computer resources



# Upscaling

Sampling properties of the fine scaled geological grid into the coarse simulation grid

Main purpose is to honour the geology of the fine scaled grid as much as possible, while reducing the number of total cells for a simulation run.





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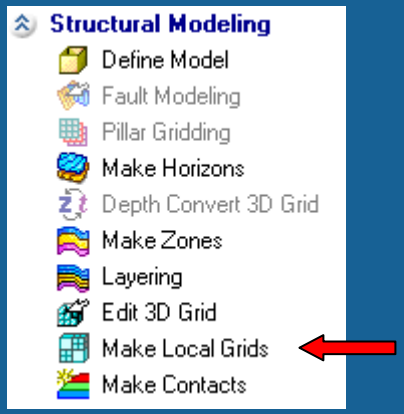
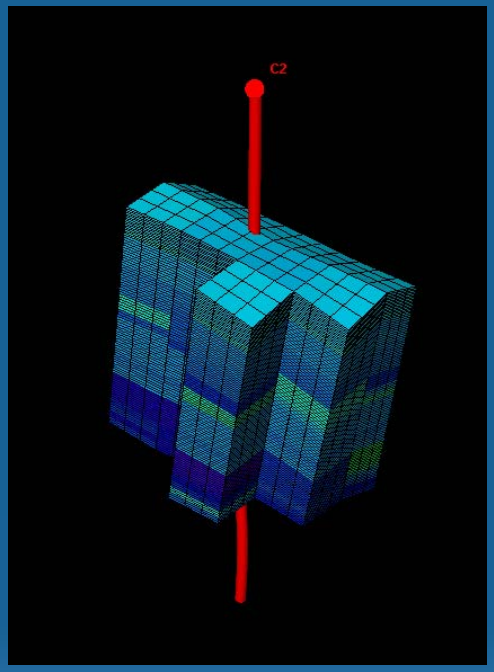
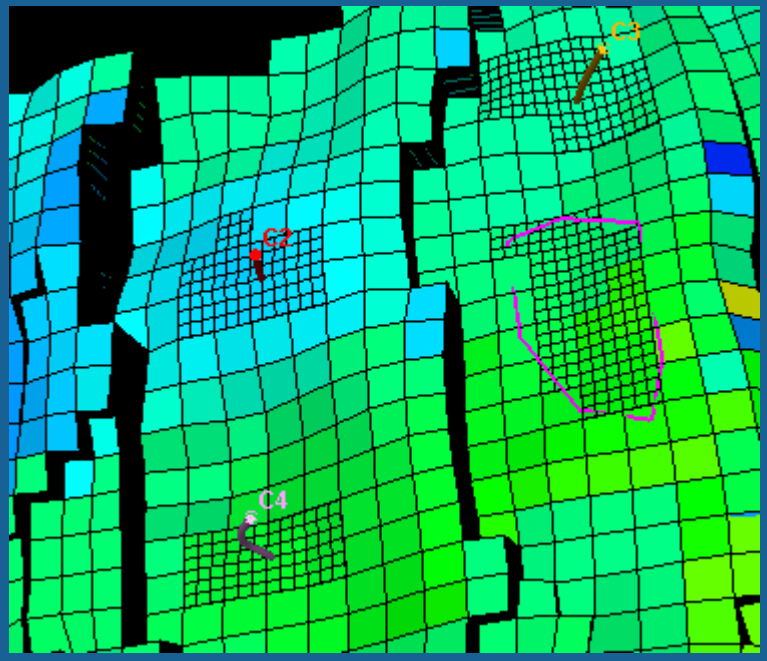
# Local Grid Refinements



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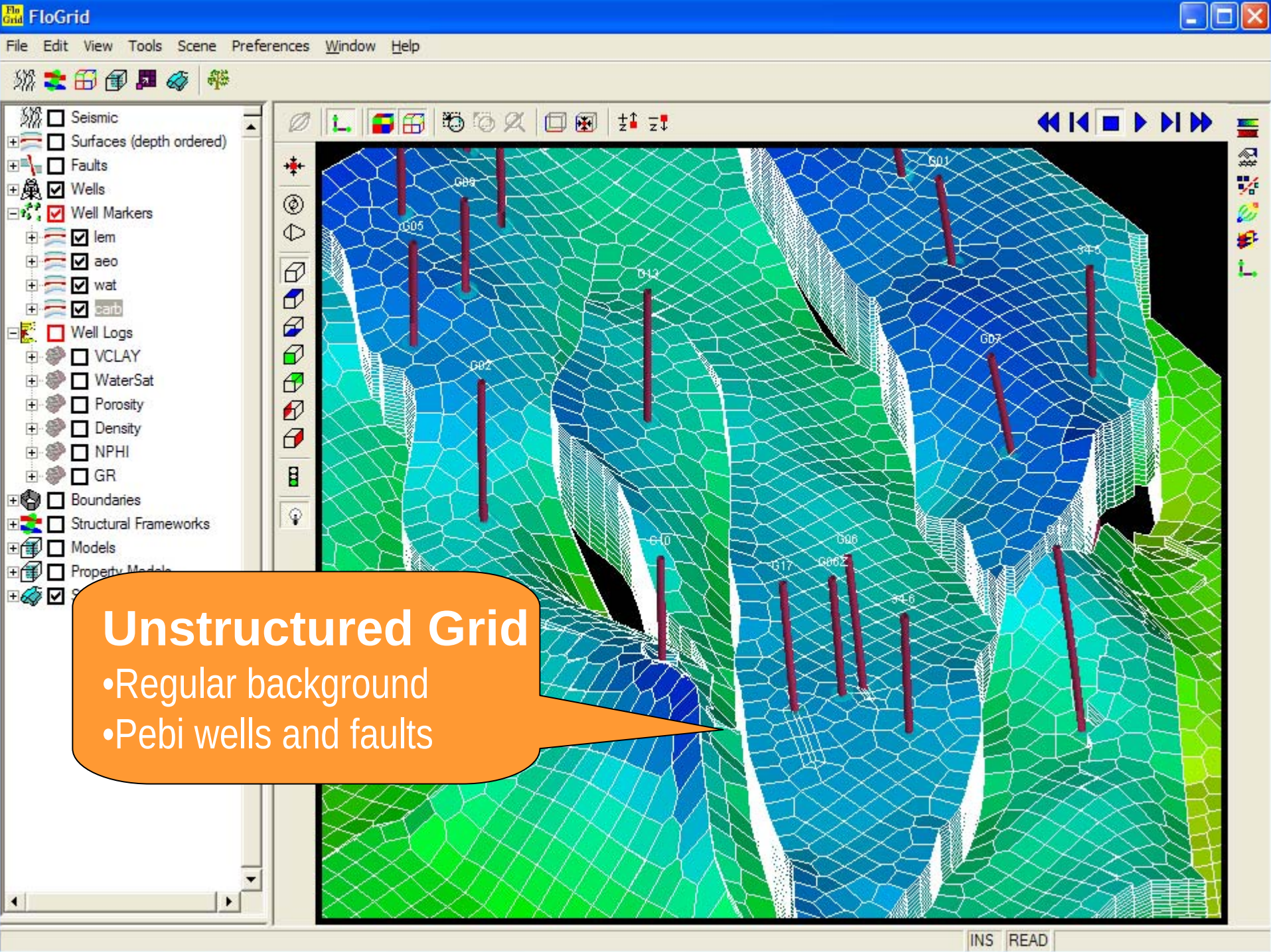
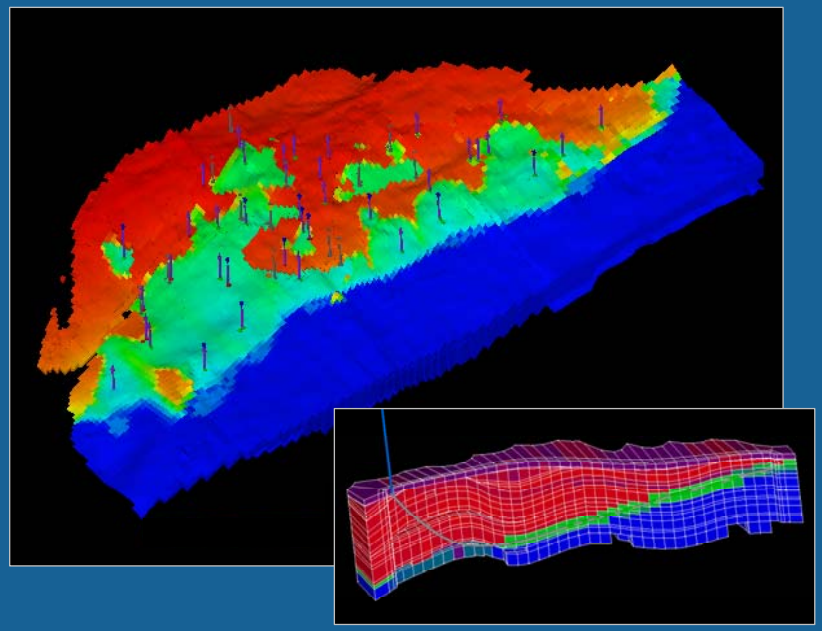



# Unstructured Grid

- Regular background
- Pebi wells and faults

# ECLIPSE Finite Difference Reservoir Simulator



- World-wide standard in reservoir simulation

- Features
  - 1-, 2-, 3-phase models
  - IMPES & fully-implicit solutions
  - Dual porosity/permeability
  - MPF-discretisation (handle tensor permeability)
  - Fully-coupled geomechanics
  - Fully-coupled, definable chemical reactions
  - Advanced well controls/models
  - Relative permeability and capillary pressure scaling and hysteresis



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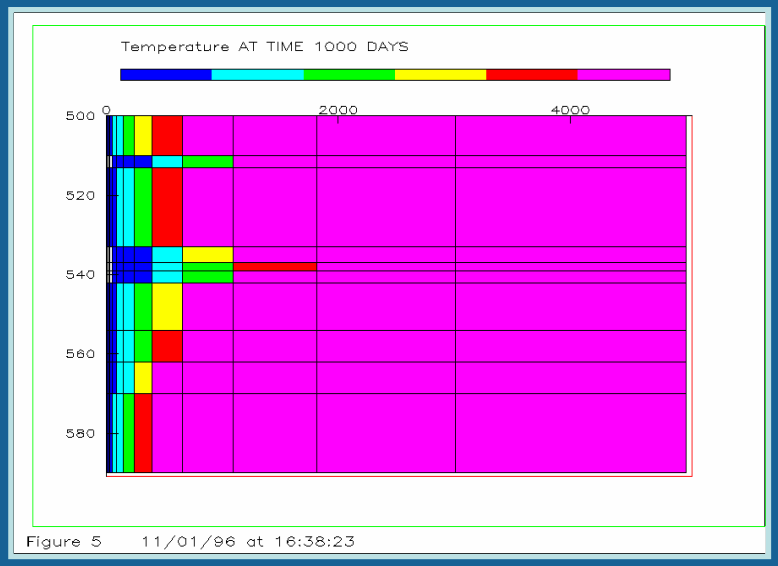
# ECLIPSE (more)




- Account for thermal effects
  - e.g. cold water injection
  - oil & water properties modified
- Tracers
  - define passive tracers to trace injected vs aquifer water
  - active tracers (decay, adsorption) (ECLIPSE Blackoil Only)
- Miscible gas injection (ECLIPSE Blackoil Only)
- API tracking (ECLIPSE Blackoil Only)
- Salinity tracking (ECLIPSE Blackoil Only)



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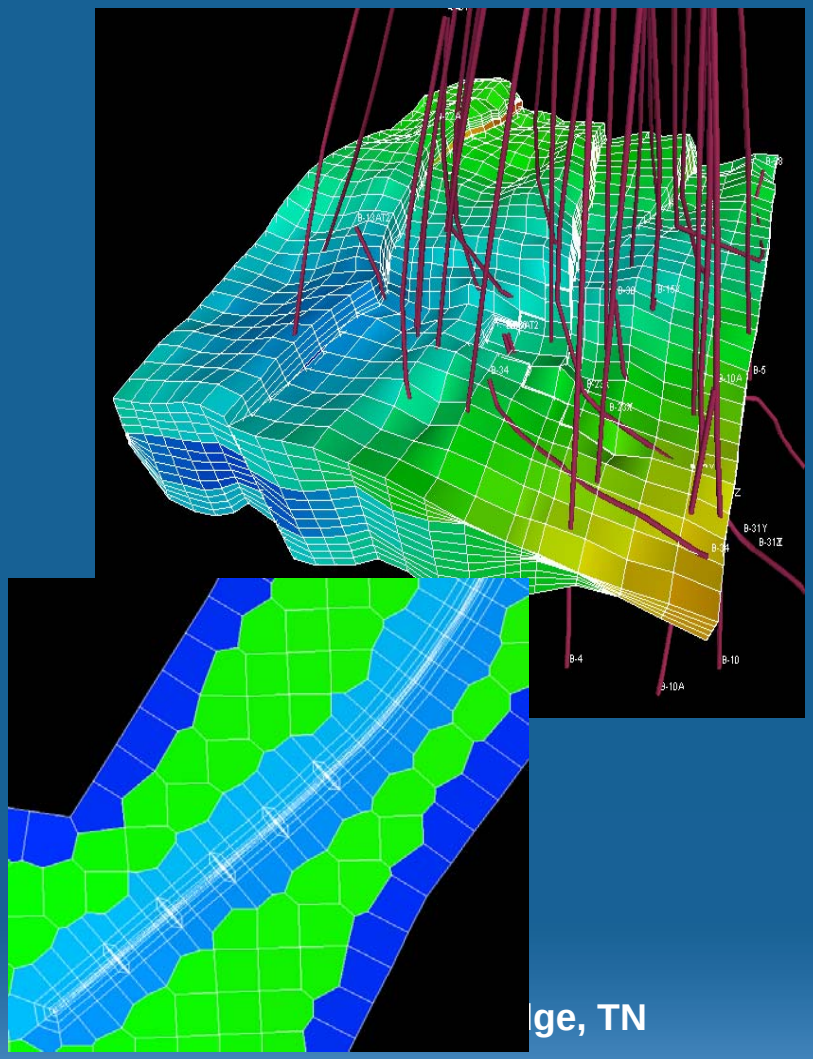
# Geometry Options



ge, TN

- Standard and advanced grids:
  - Corner-point grids
  - Grid refinement
    - Cartesian & Radial
    - Dual timestepping or fully coupled solutions of refined grid (ECLIPSE Blackoil Only)
- Non-neighbour connections
- Unstructured (PEBI) grids

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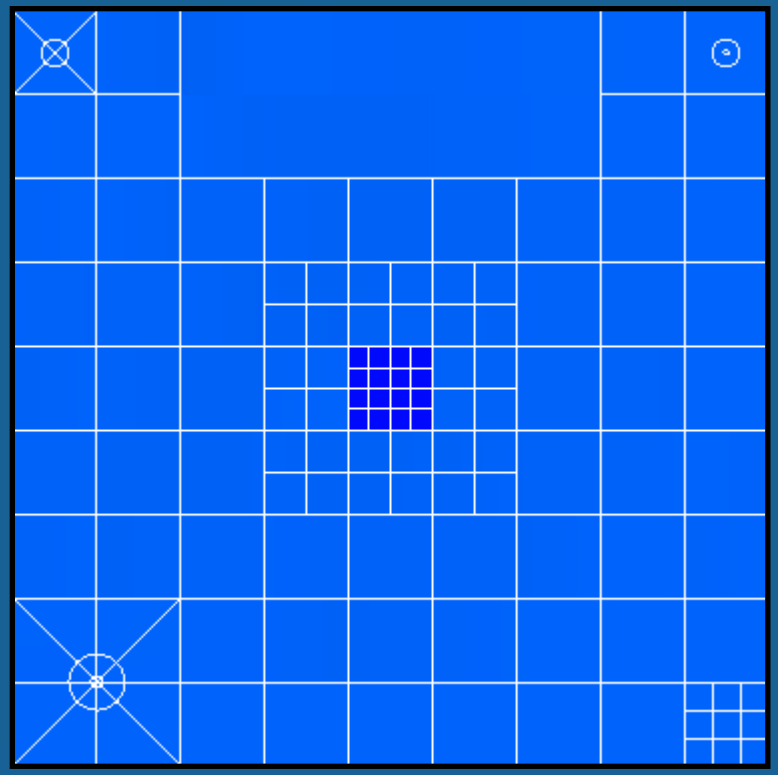
# ECLIPSE - Local Grid Refinement & Coarsening



- Enhance grid definition around areas of interest
- Local grids, radial or Cartesian, with more layers than global model
  - Gain efficiency by solving local grids independently of global grid for heavily refined grids
  - Use fully-coupled solution method for moderate refinements
- Amalgamate areas of little interest/activity into a single cell with grid coarsening



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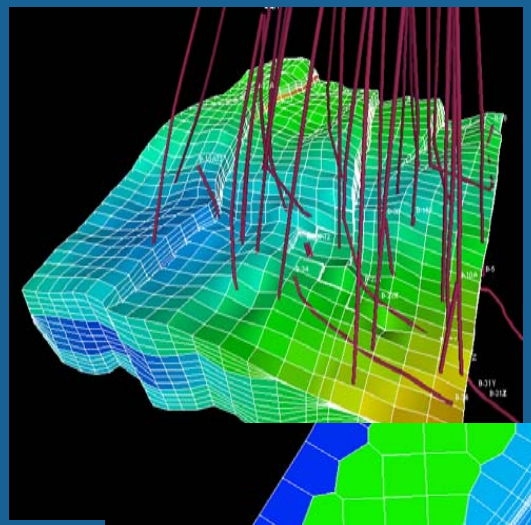
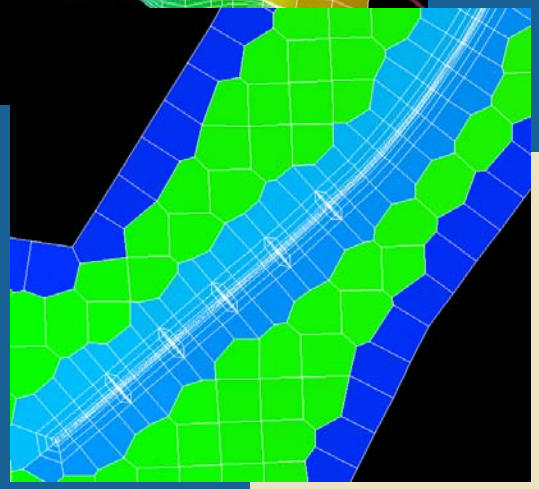
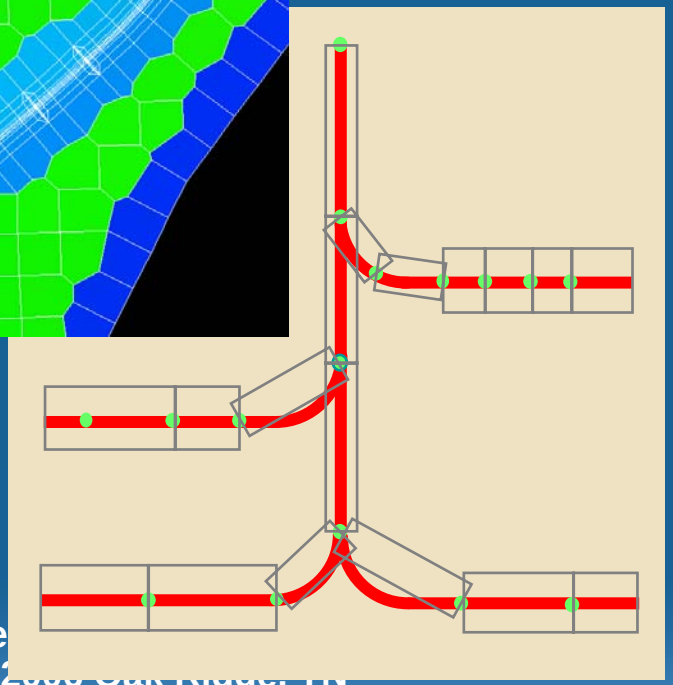
# Multisegmented Wells







- Deviated and multi-branch horizontal wells can be modelled properly
  - Wellbore is split into segments
  - Each segment has its local pressure, fluid densities, and phase velocities
  - Segment topology honours well path
  - Segments can be outside of reservoir model



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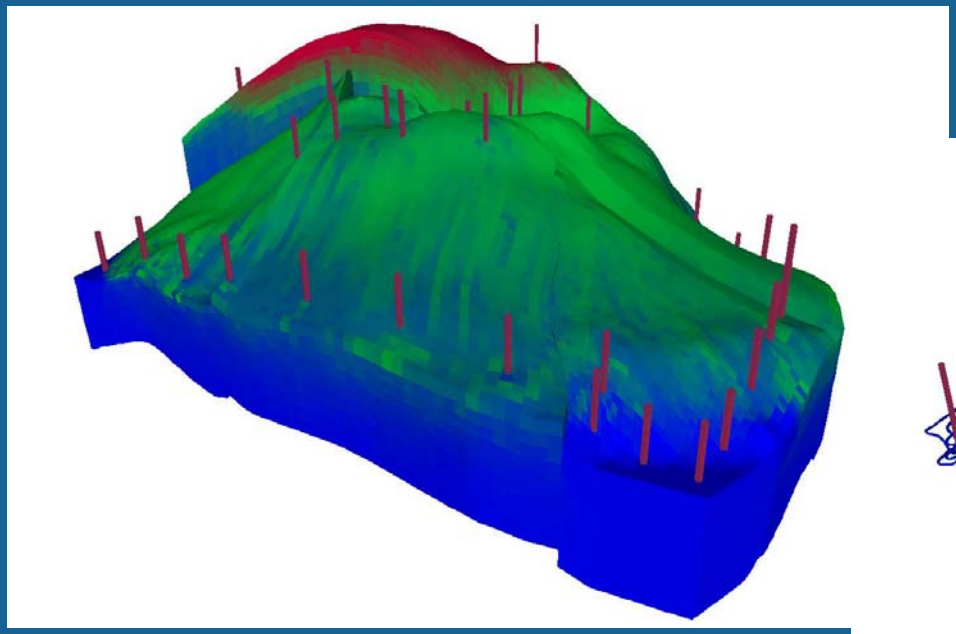
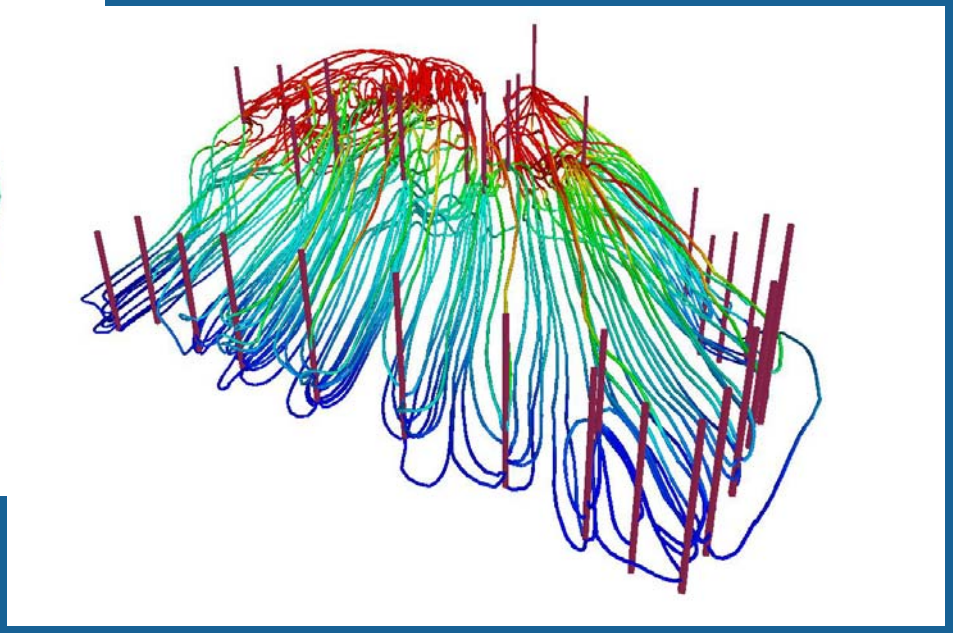
# Streamline Simulation (FrontSim)





- Improved understanding
- Sharp delineation of saturation fronts
- Better decision making



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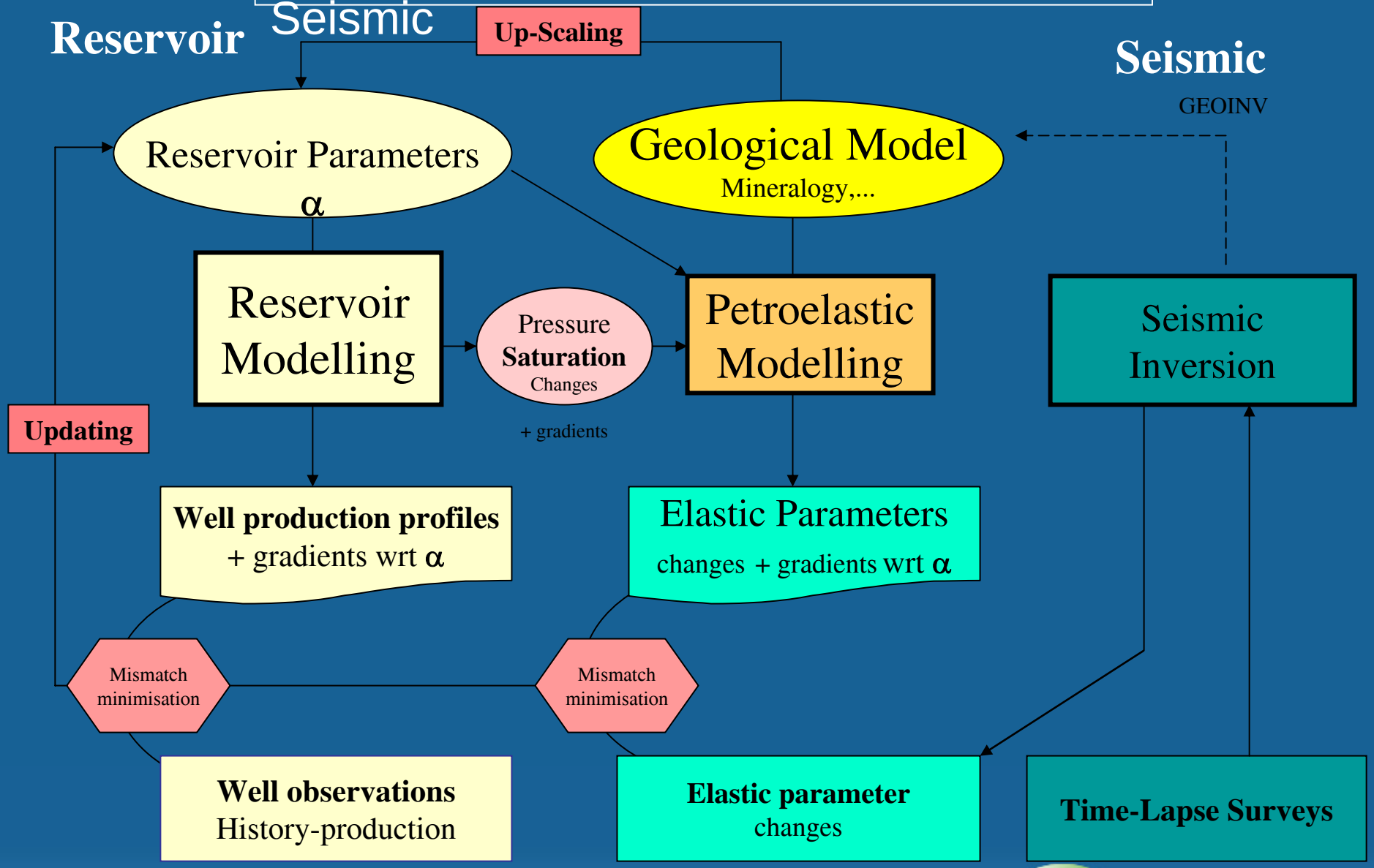
# History-Matching Using Time-Lapse Seismic



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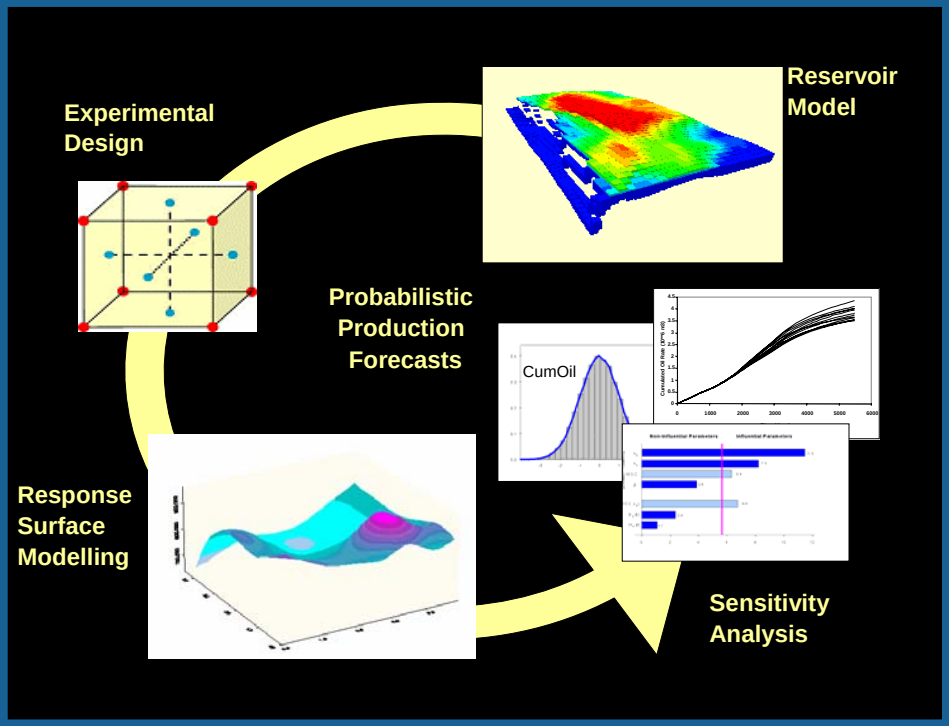
# Accounting for Uncertainty in Reservoir Simulation – COUGAR

- COUGAR can be used with a history matched model or new field for Probabilistic Production Forecasts
  - Account for uncertainties in reservoir development economics
  - Rapidly determine, with greater certainty, the range of an asset value



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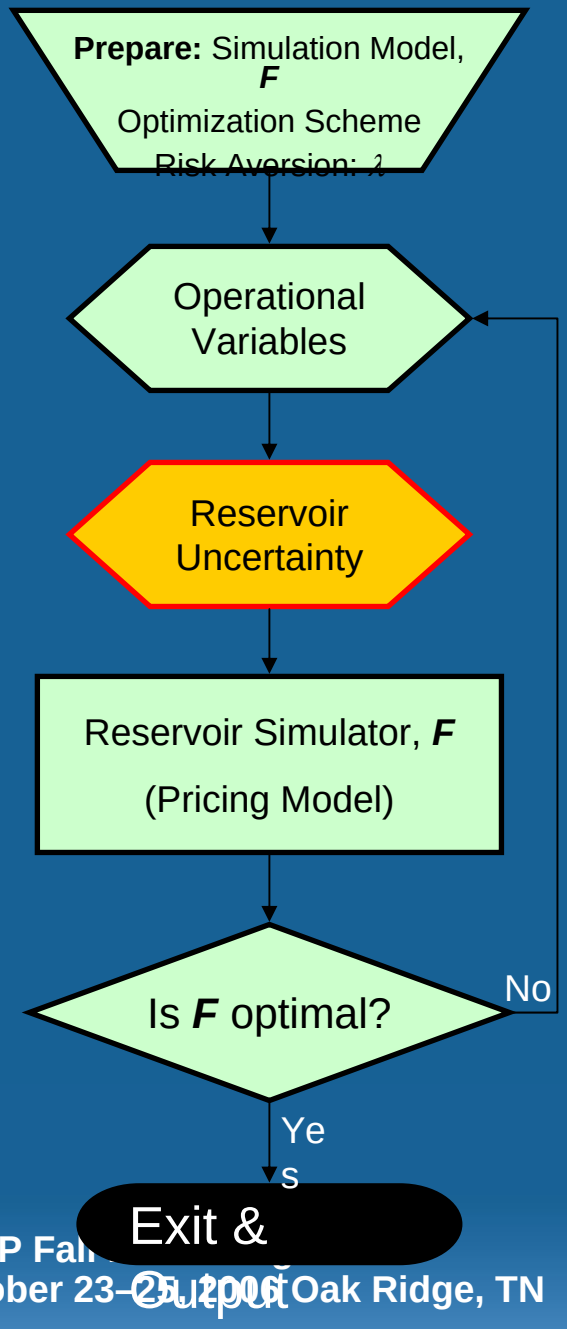
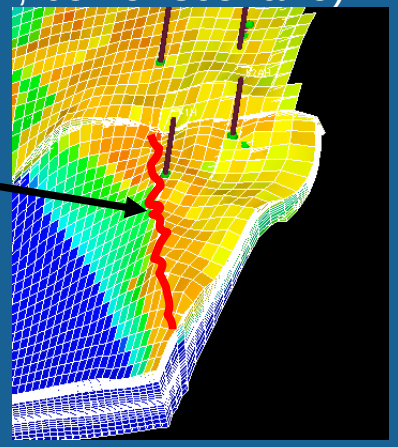
# Optimization of Reservoir Operations – Accounting for Uncertainty



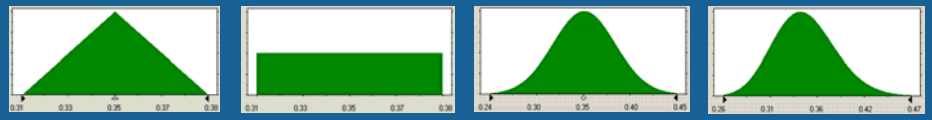

- Refers to anything that impacts on model initialization. For example:
  - Fault transmissibility
  - Aquifer size and strength
  - Properties (by region, box or scenario)

e.g…

MULTFLT = ?



- Each uncertainty has an associated PDF of any desired form:





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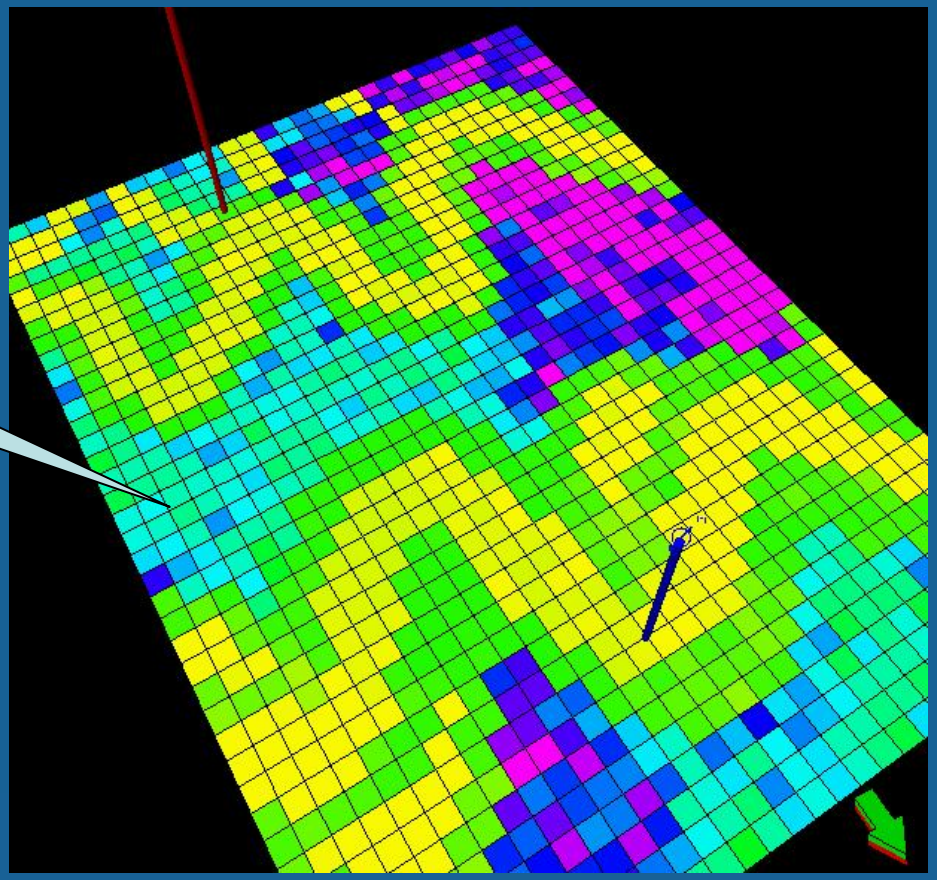
# Why does an Integrated Modeling Workflow matter?

Original Geological Model





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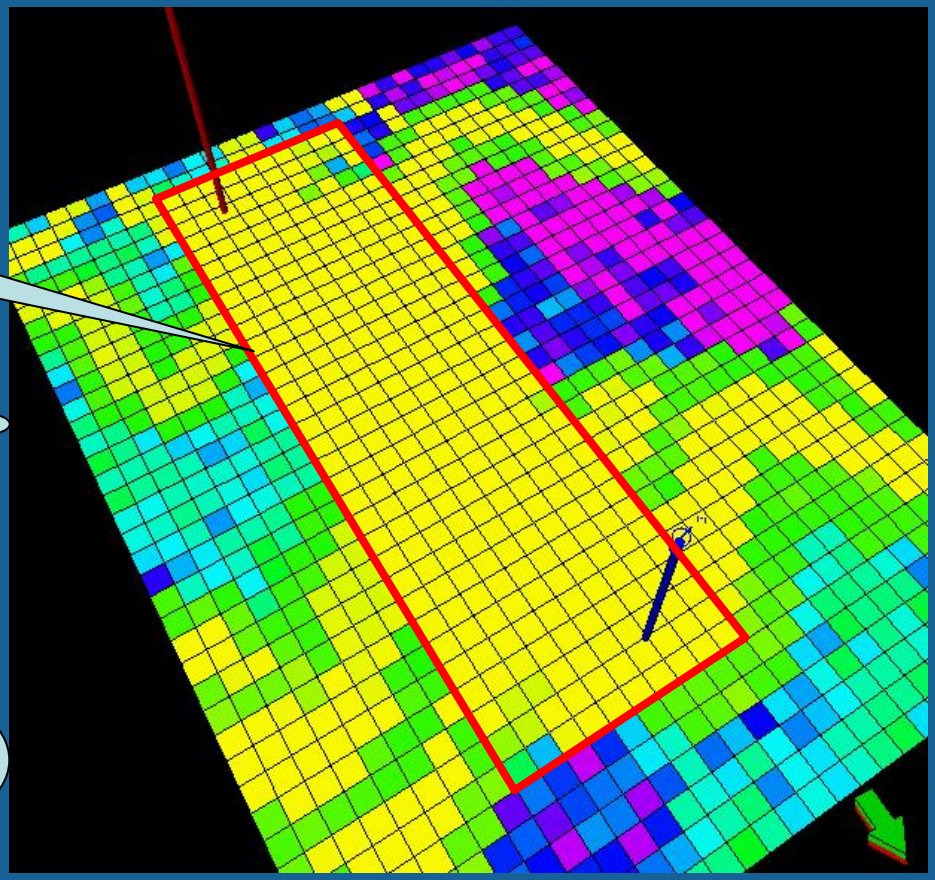
# Why does an Integrated Modeling Workflow matter?

Wells show communication ⇒ engineering modification



Geologically reasonable?
Predictive power?



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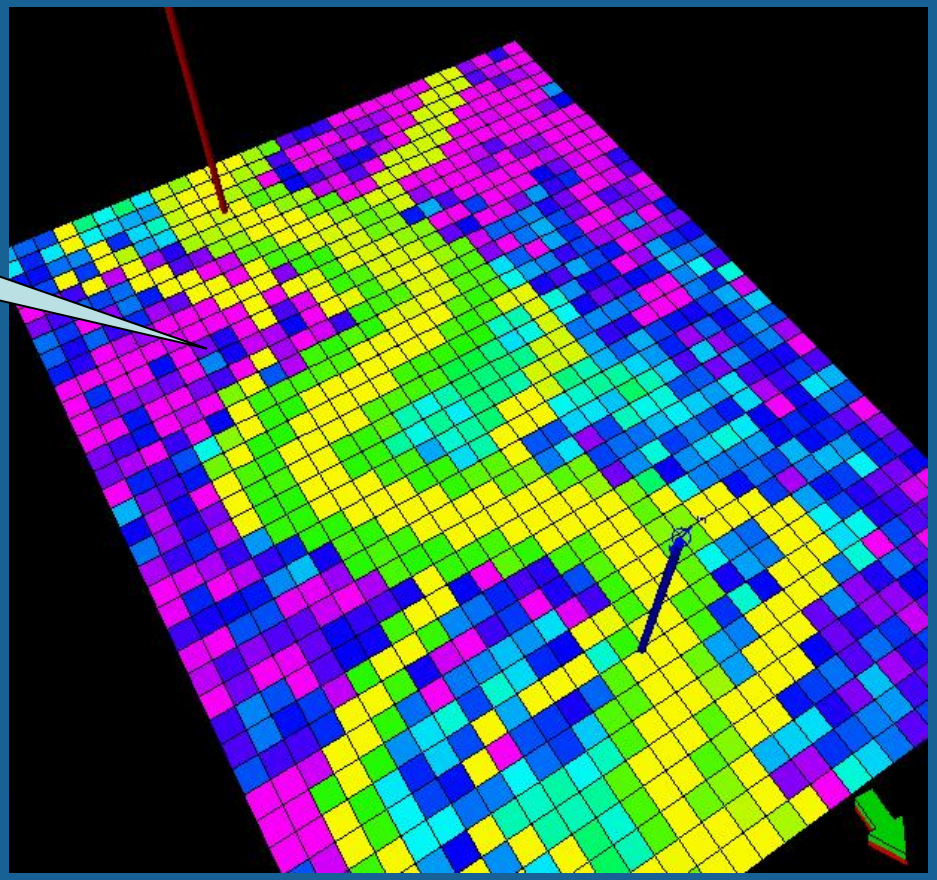
# Value of Integrated Modeling Workflow

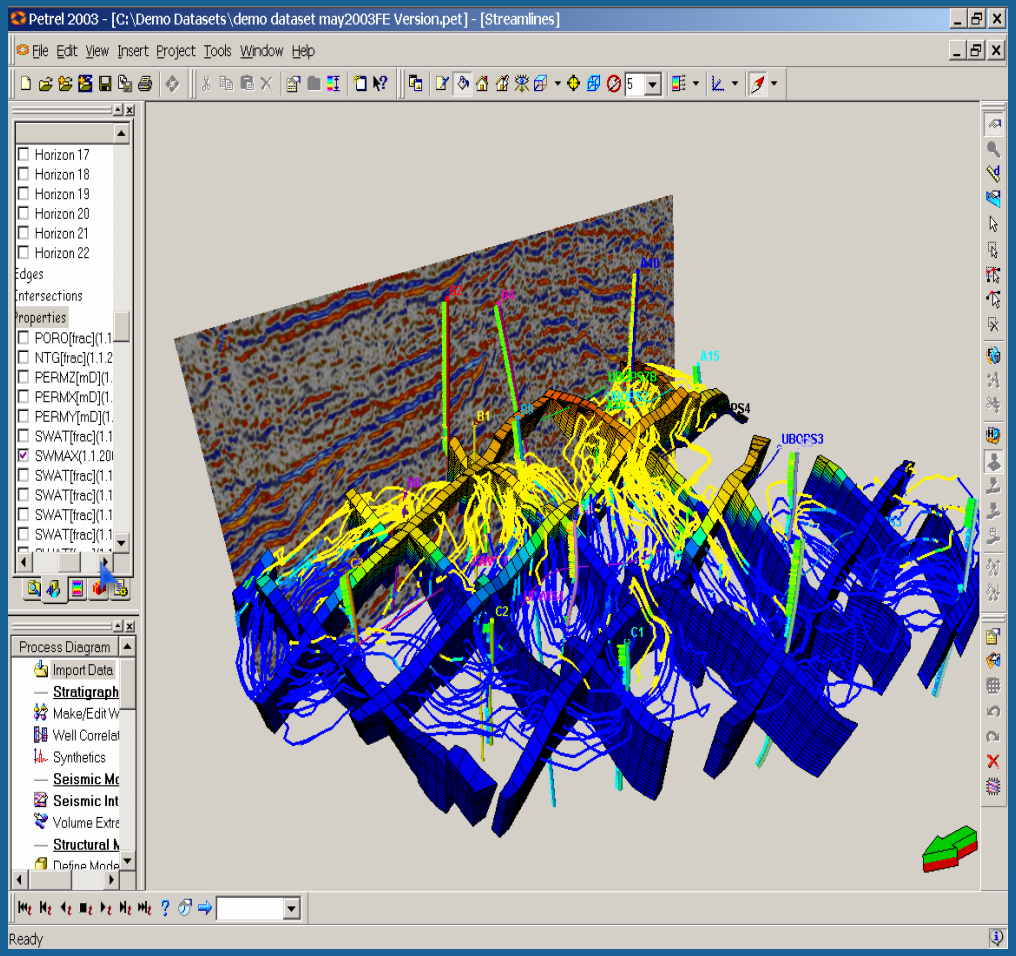
Geological modification – change channel direction



In an integrated environment, this is much easier to do, so more likely to happen!

# State-of-Practice Reservoir Engineering

- Integration
  - Geophysics to Reservoir Engineering
- Usability
  - Geologists to reservoir engineers
- Repeatability
  - Workflow editor for rapid update



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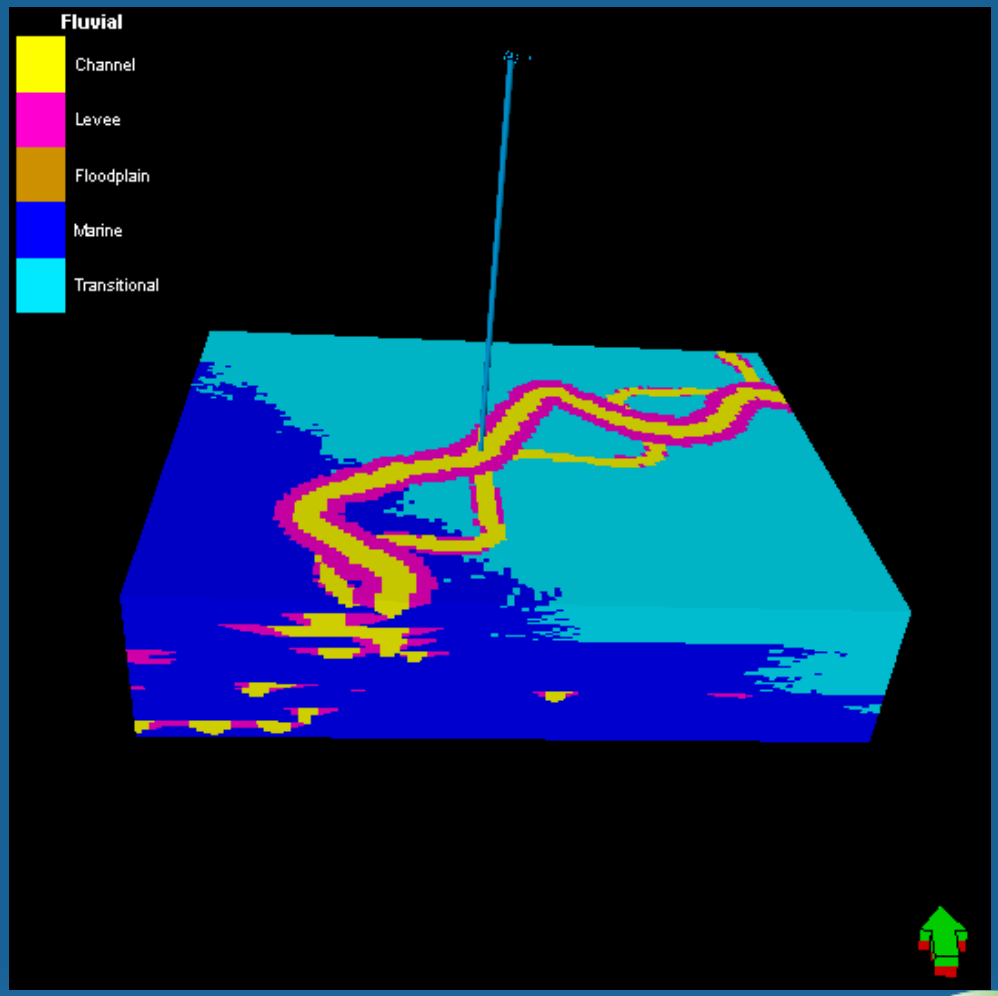
# Aquifer Storage Recovery (ASR) in Fluvial Aquifer System




**ERSP Fall PI Meeting**
**October 23–25, 2006 Oak Ridge, TN**

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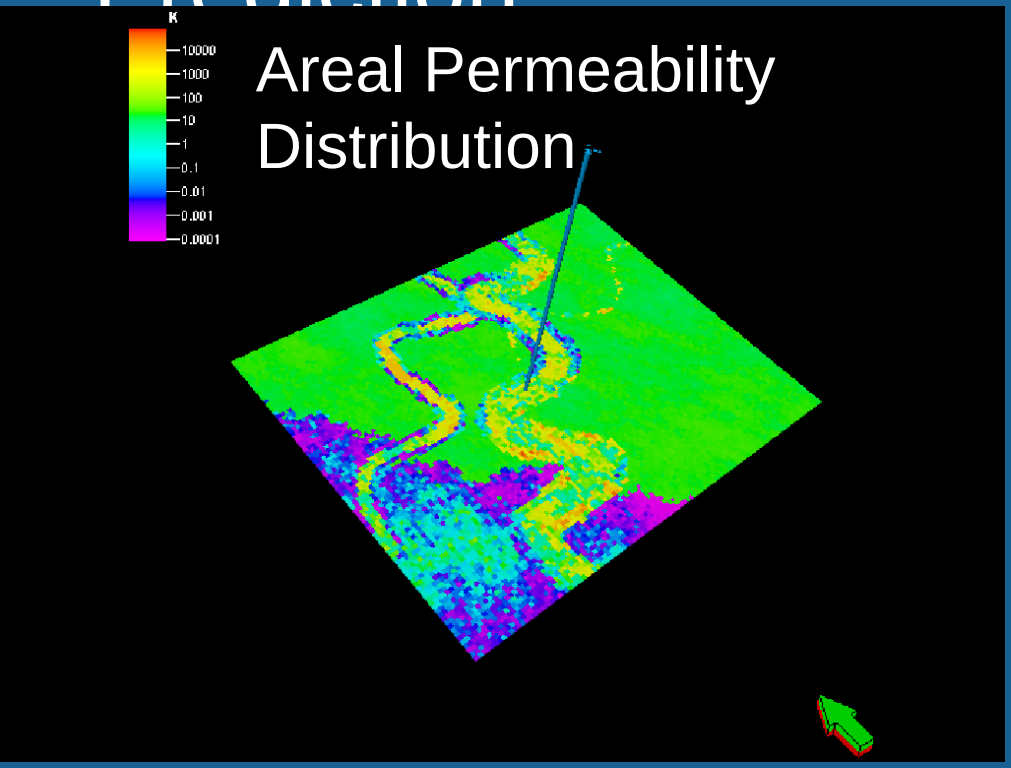
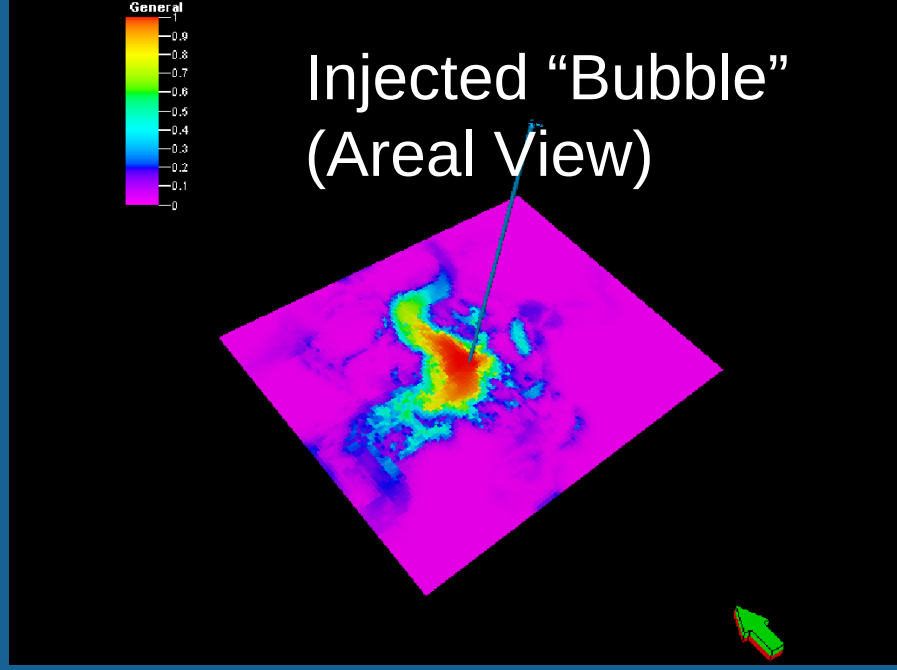
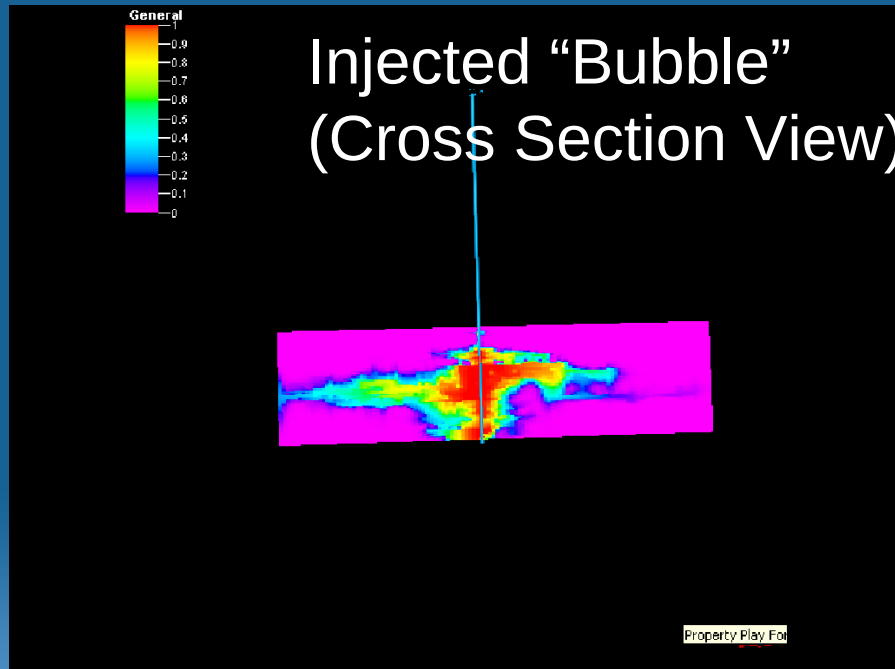
# Realistic ASR Modeling and Prediction

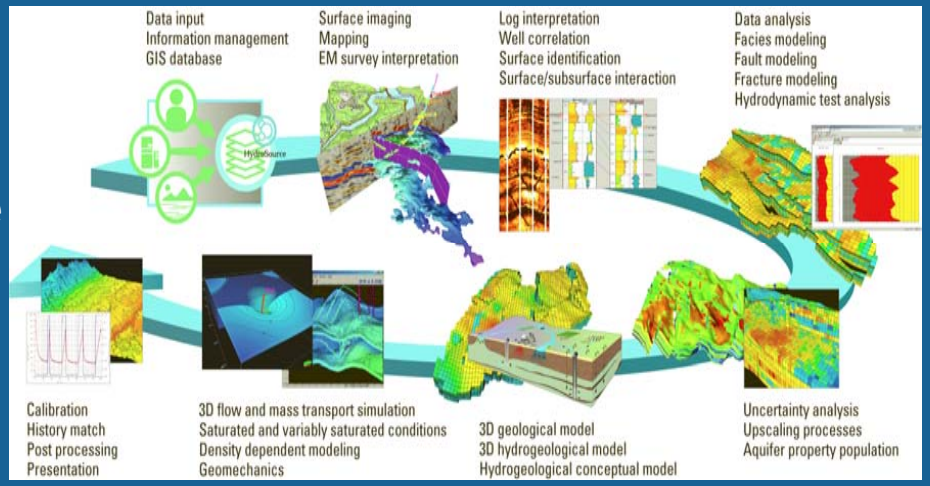


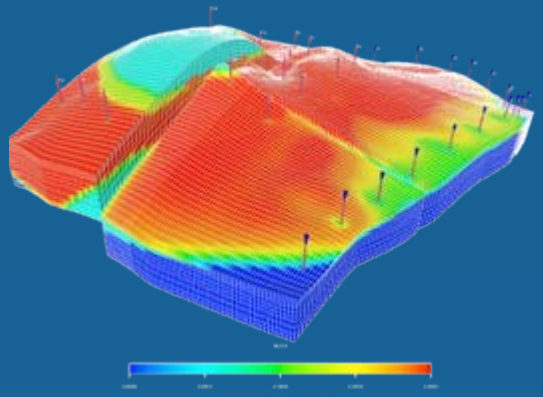



# Summary – Advanced Groundwater Characterization Using Oilfield Technology

- Fresh water availability and reliability growing issue in many places
- Increased usage, water quality degradation, moving more to conjunctive use of surface and ground water
- With decreasing resource, increased need for management
- Effective management requires accurate understanding – effective characterization and decision-making
- **Opportunity to utilize existing, mature & advanced technology developed for the oil industry (money already spent on R&E)**
- **Cross-discipline compatibility – evaluation and management of subsurface fluids**





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