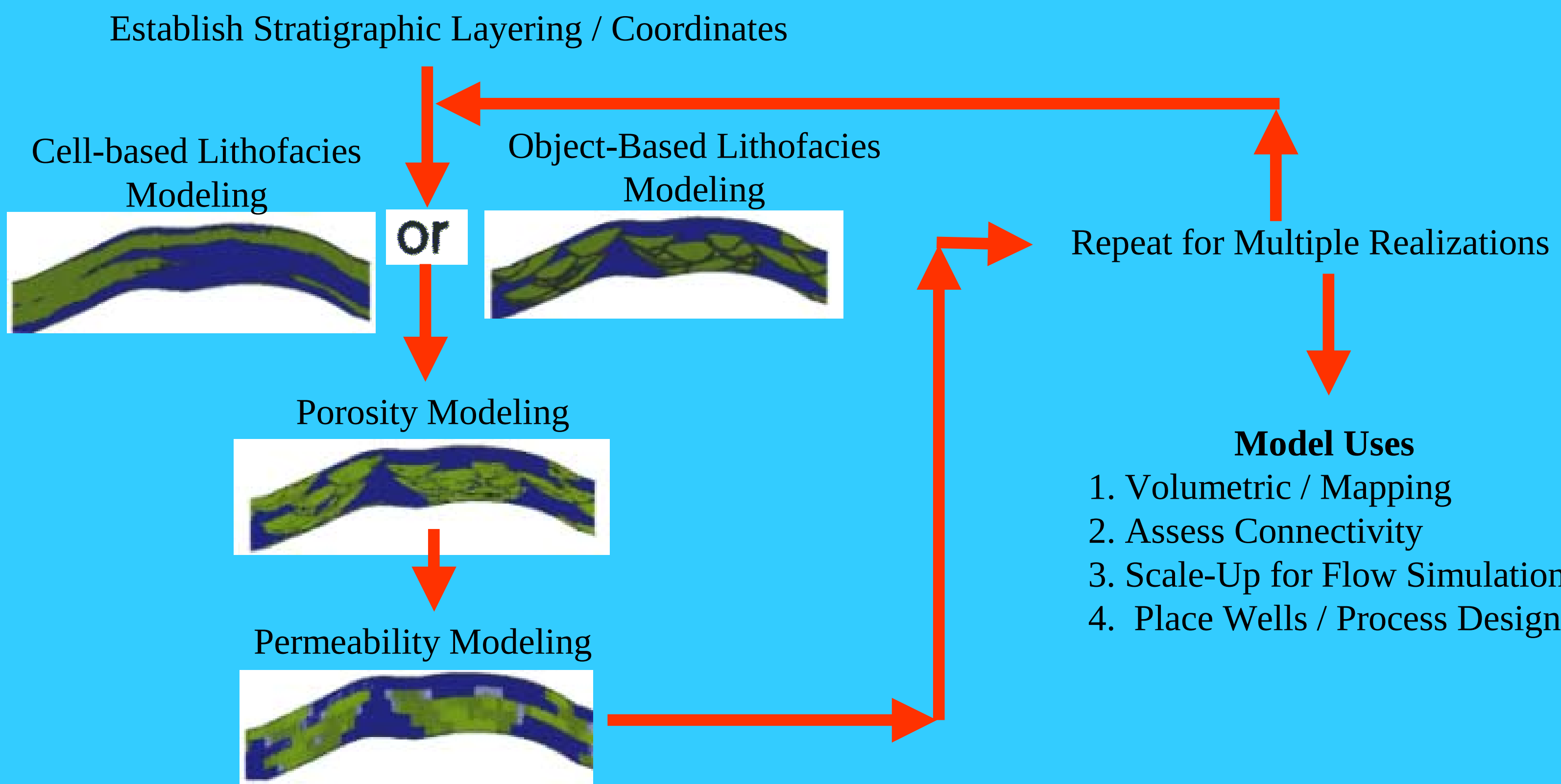
Case Studies / Modeling Tips

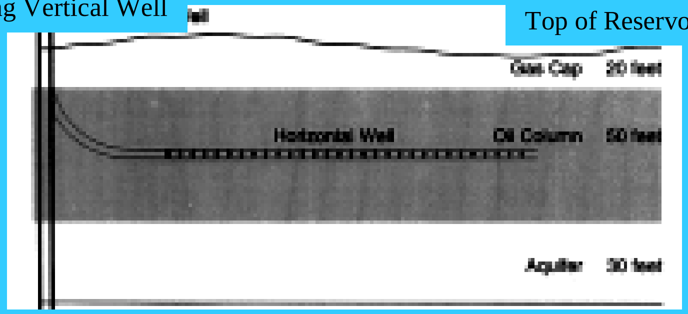
- Sequential Approach to Reservoir Modeling
- Question / Answer Time
- A Small Example
- Glimpses of Case Studies

Reservoir Modeling

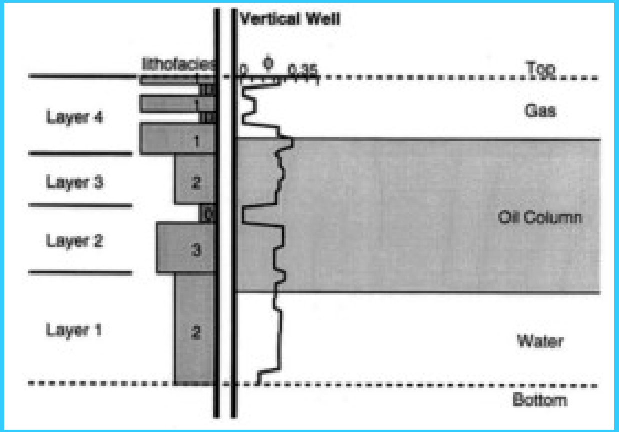


Main geostatistical modeling flow chart: the structure and stratigraphy of each reservoir layer must be established, the lithofacies modeled within each layer, and then porosity and permeability modeled within each lithofacies.

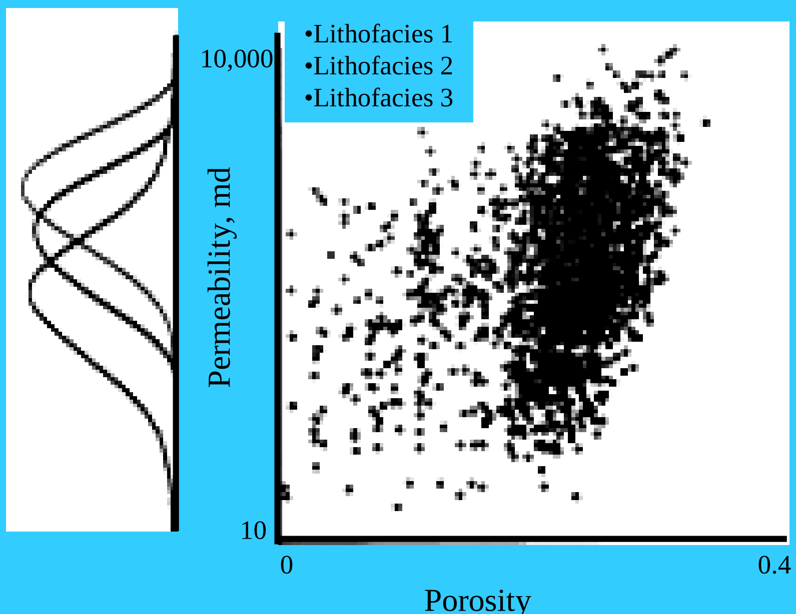
Introductory Example



- Fashioned after a real problem and the geological data is based on outcrop observations
- A horizontal well is to be drilled from a vertical well to produce from a relatively thin oil column.
- The goal is to construct a numerical model of porosity and permeability to predict the performance of horizontal well including (1) oil production, (2) gas coning, and (3) water coning.



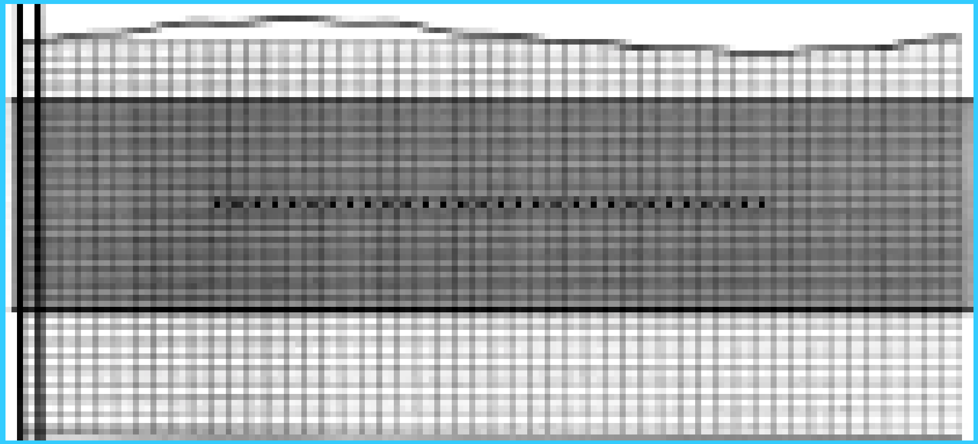
Introductory Example - Petrophysical Data



Code	Lithofacies	Average Perm.	Coefficient of variation	$K_v:K_h$ ratio
0	Coal and Shale	1 md	0.00	0.1
1	Incised Valley Fill Sandstone	1500 md	1.00	1.0
2	Channel Fill Sandstone	500 md	1.50	0.1
3	Lower Shoreface Sandstone	1000 md	0.75	0.8

Permeability characteristics of each lithofacies: the coefficient of variation is the average permeability divided by the standard deviation, K_v is the vertical permeability, and K_h is the horizontal permeability.

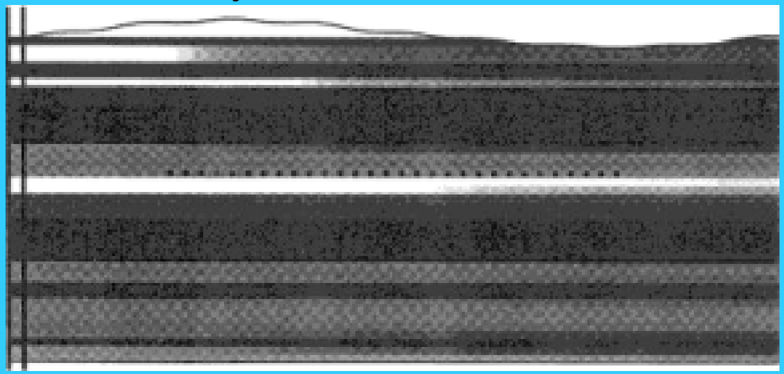
Flow Simulation



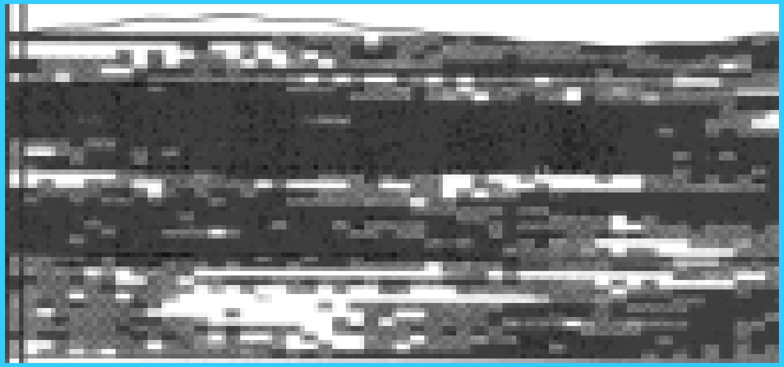
Gridding for flow simulation. For numerical efficiency, the vertical gridding is aligned with the gas-oil fluid contact and the oil-water fluid contact. The black dots illustrate the location of the proposed horizontal well completions. Representative three-phase fluid properties and rock properties such as compressibility have been considered. It would be possible to consider these properties as unknown and build that uncertainty into modeling; however, in this introductory example they have been fixed with no uncertainty.

Simple Geologic Models

Layercake Model



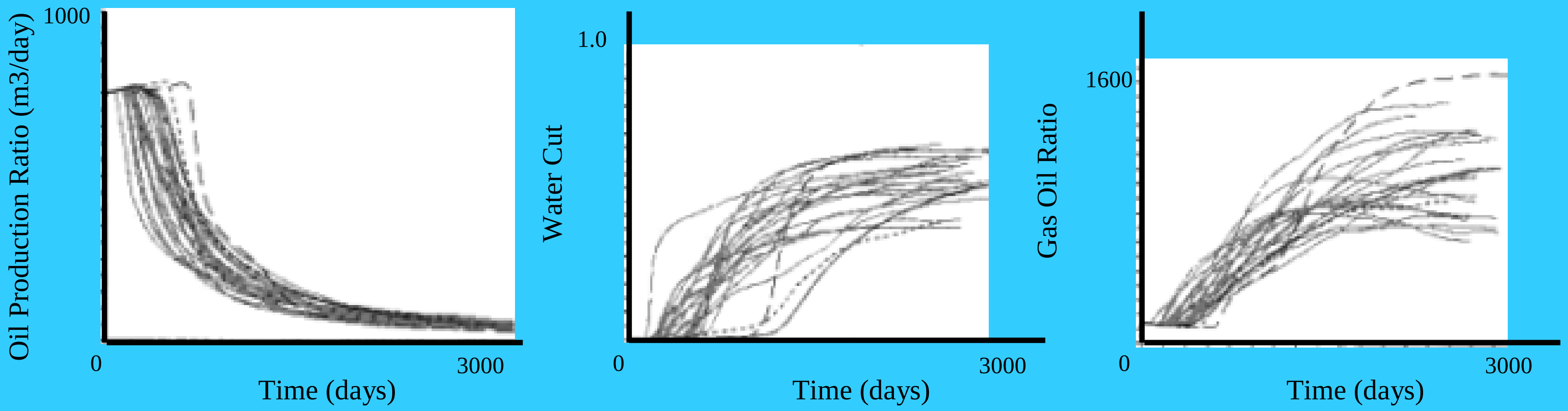
Gaussian Simulation Model



Smooth Model

Three simple assignments of rock properties (a) a “layercake” or horizontal projection model, (b) a smooth inverse distance model, and (c) a simple Gaussian simulation.

Simple Geologic Models: Flow Results



Flow results: layercake model - solid line; smooth model - long dashes; simple geostats model -- short dashes.

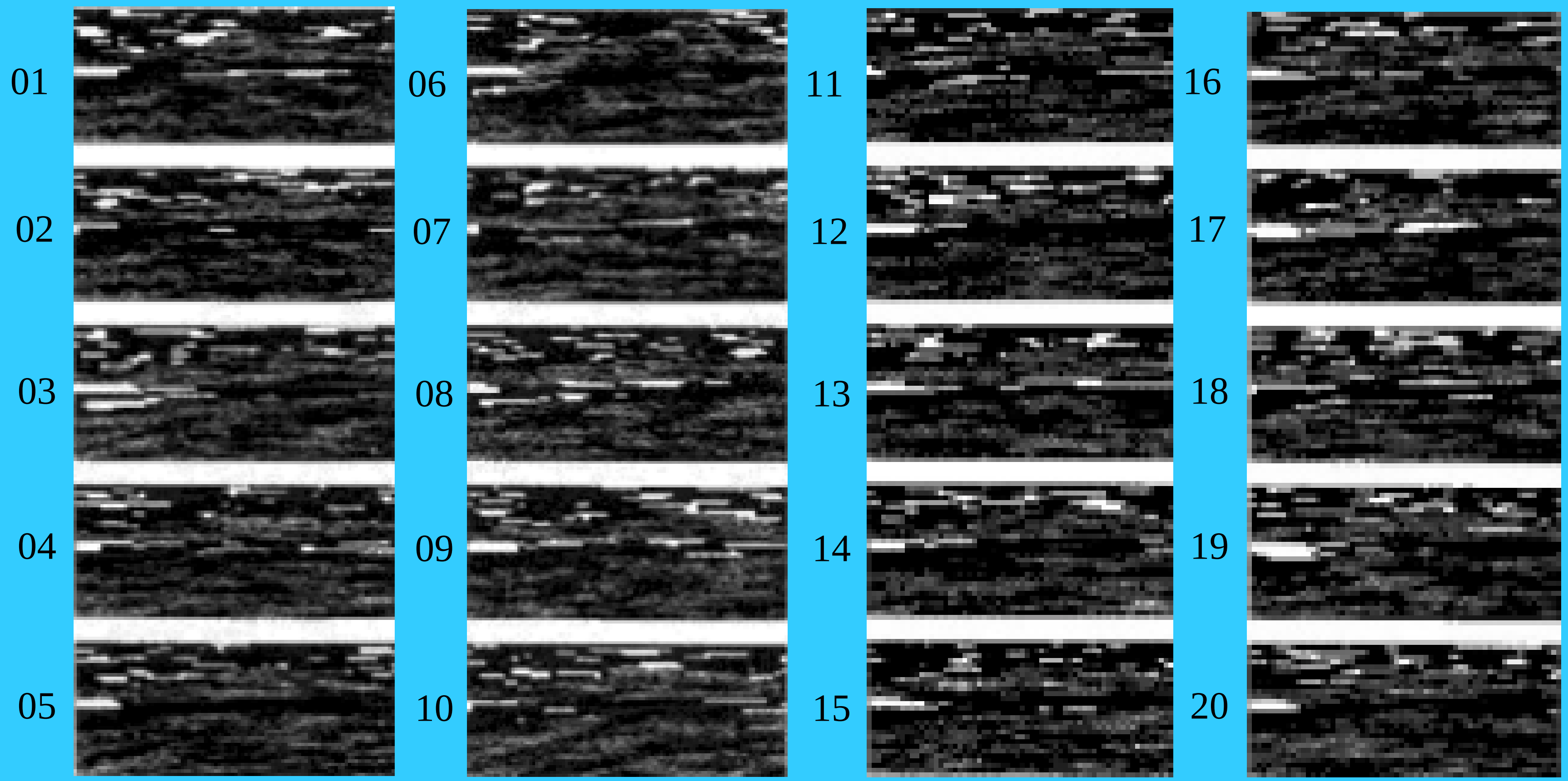
Better Geologic Model

(a) Geostatistical Model

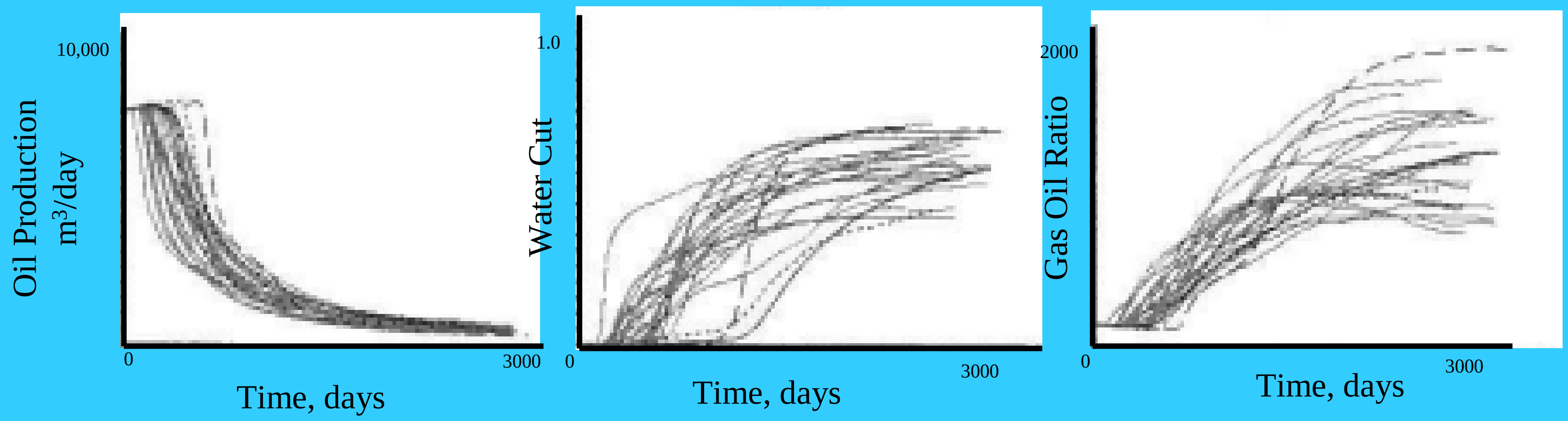
(b) Geostatistical Model - Flow Grid

The first geostatistical realization shown on the geological grid and the flow simulation grid

Multiple Realizations

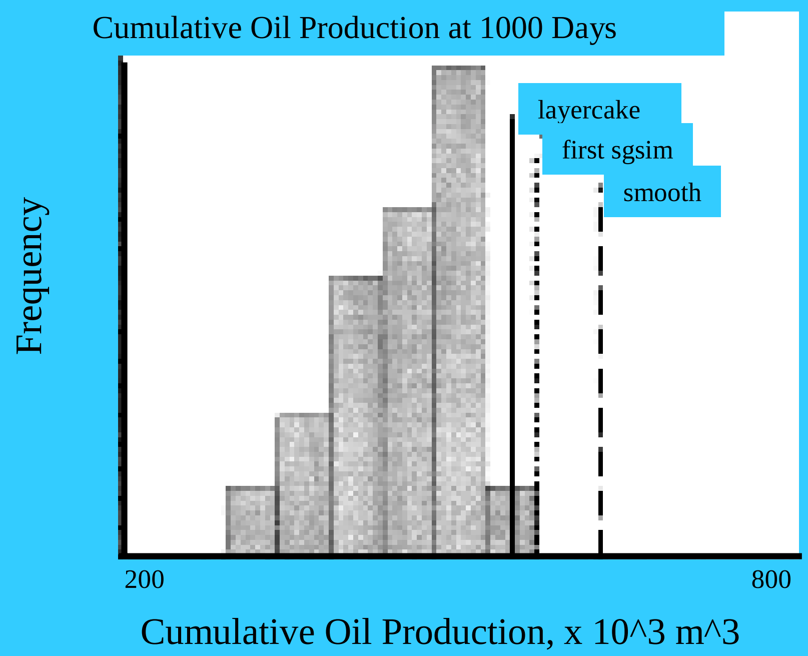


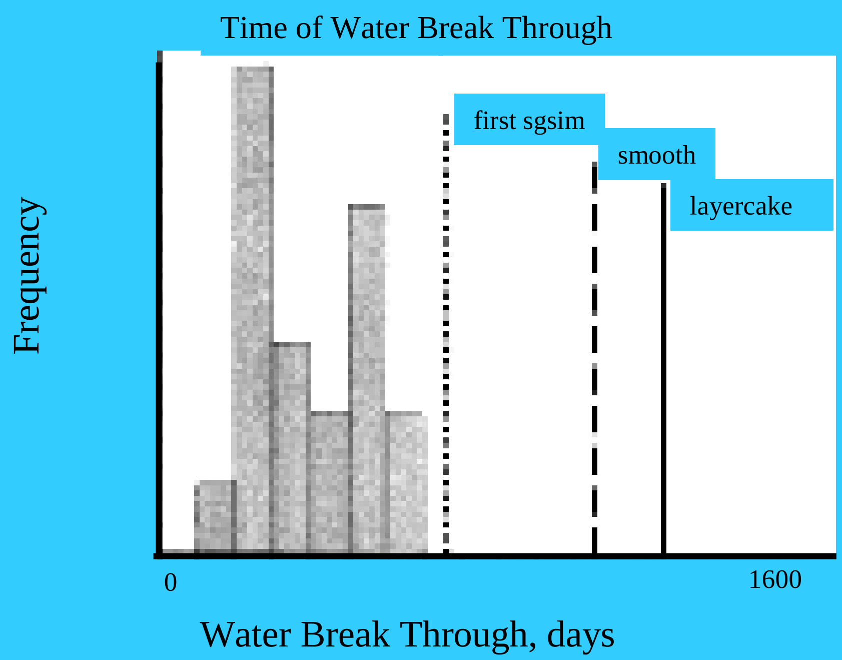
Geologic Models - Flow Results



Flow results from 20 geostatistical realizations (solid gray lines) with simple model results superimposed

Uncertainty



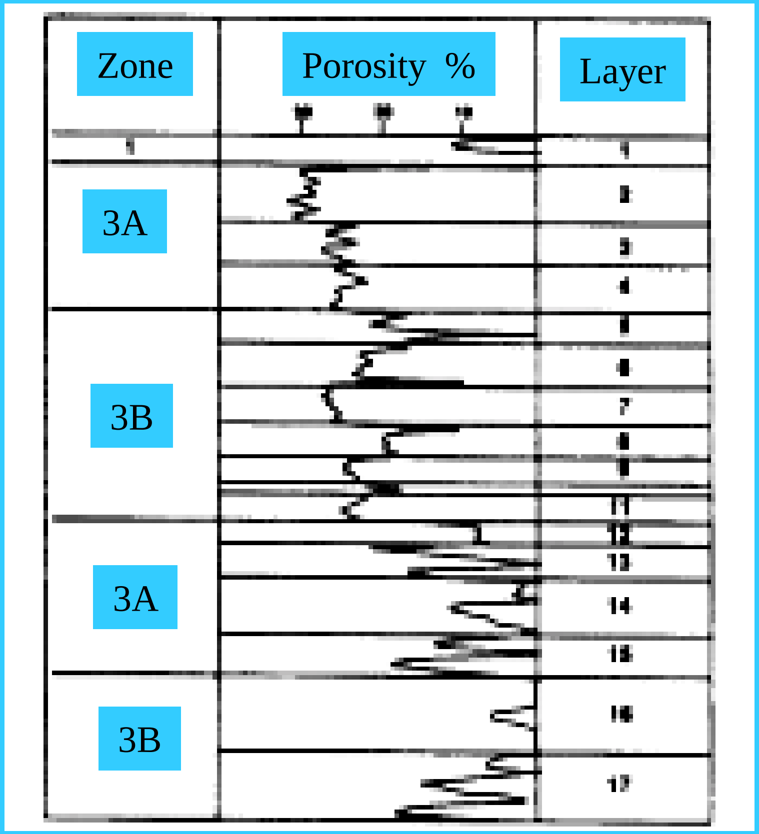


The cumulative oil production after 1000 days and the time to water breakthrough.

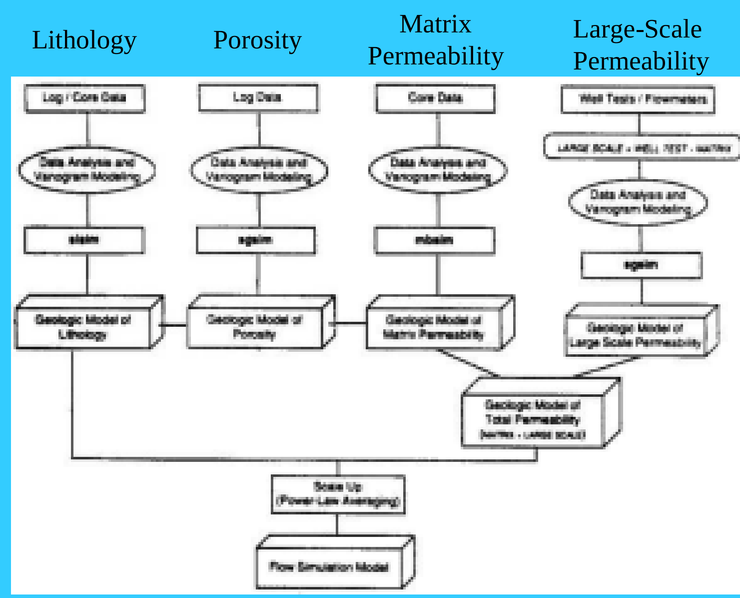
Note the axis on the two plots. There is a significant difference between the simple models and the results of geostatistical modeling (the histograms).

Major Arabian Carbonate Reservoir

- GOSP 2 & 7 Area study commissioned by Saudi Aramco
- SPE29869 paper *Integrated Reservoir Modeling of a Major Arabian Carbonate Reservoir* by J.P. Benkendorfer, C.V. Deutsch, P.D. LaCroix, L.H. Landis, Y.A. Al-Askar, A.A. Al-AbdulKarim, and J. Cole
- Oil production from wells on a one-kilometer spacing with flank water injection. There has been significant production and injection during the last 20 years
- This has had rapid and erratic water movement uncharacteristic of the rest of the field $\mapsto$ reason for building a new geological and flow simulation models



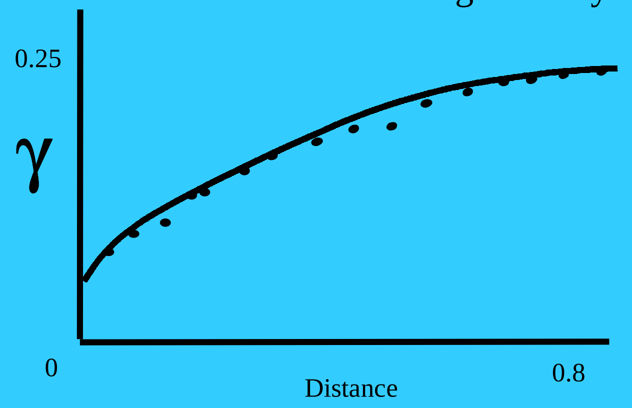
Modeling Process



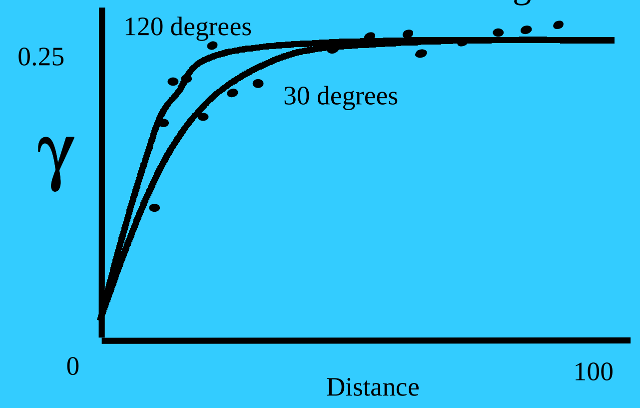
- Standard GSLIB software (because it was for Saudi Aramco)
- Novel aspect was modeling permeability as the sum of a matrix permeability and a *large-scale* permeability
  - fractures
  - vuggy and leached zones
  - bias due to core recovery
- Typical modeling procedure that could be applied to other carbonates and to clastic reservoirs

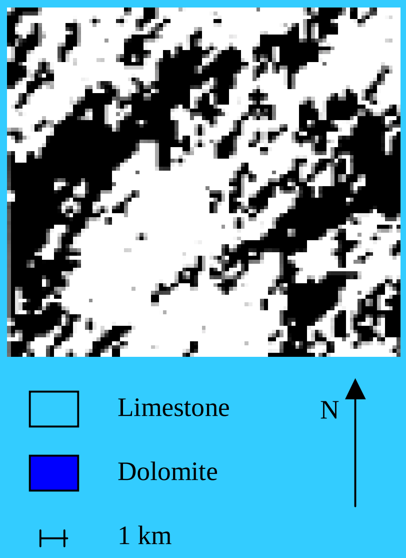
Indicator Simulation of Lithology

Vertical Indicator Variogram: Layer 8



Horizontal Indicator Variogram: Layer 8



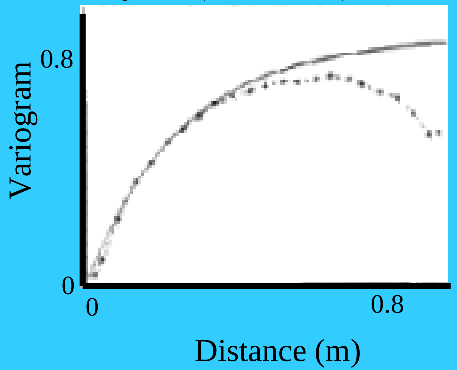


Presence / absence of limestone / dolomite was modeled with indicator simulation (SISIM) on a by-layer basis

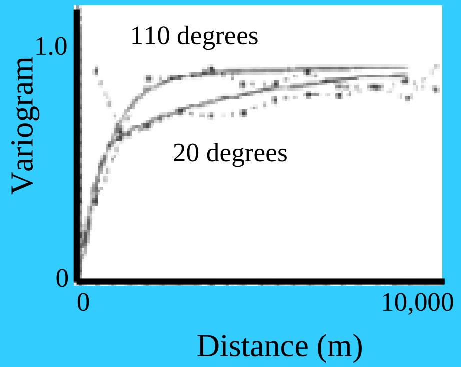
Gaussian Simulation of Porosity

- Variogram model for porosity in limestone:

Vertical Porosity Variogram
Layer 8 (Limestone)

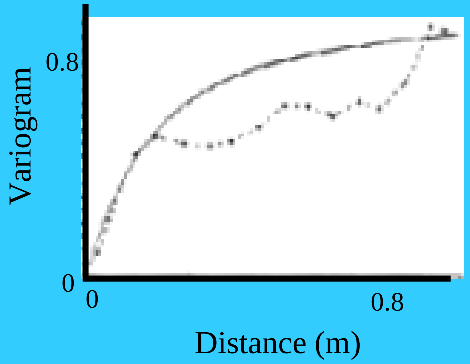


Horizontal Porosity Variogram
Layer 8 (Limestone)

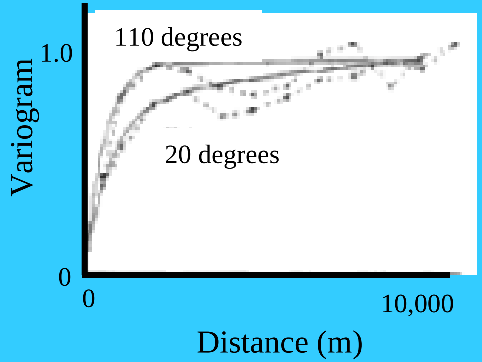


- Variogram model for porosity in dolomite:

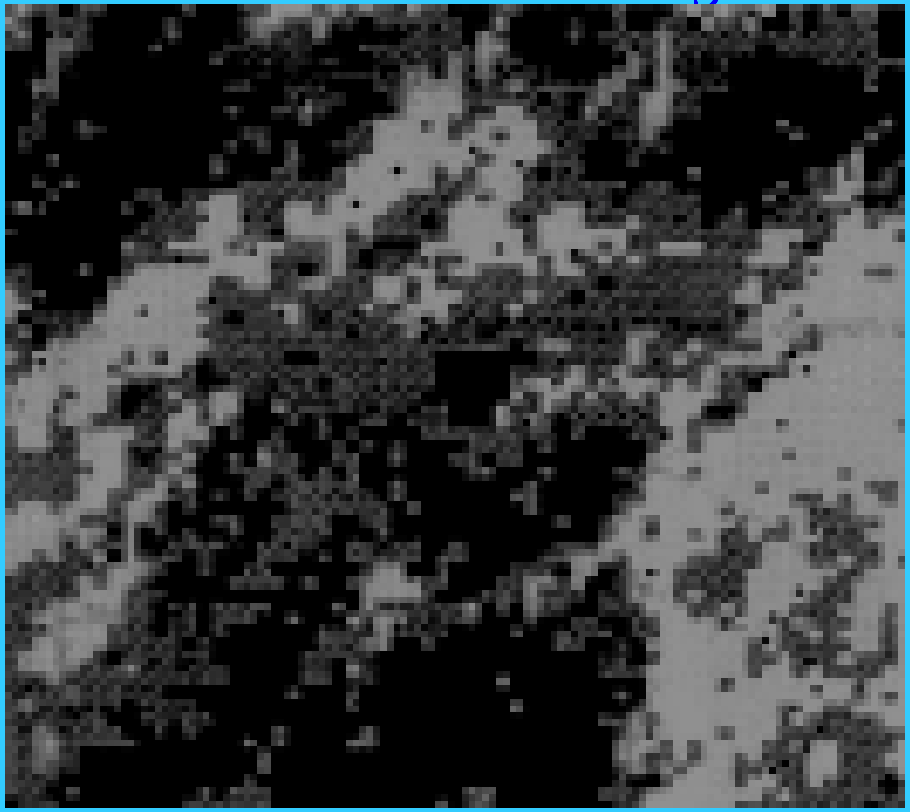
Vertical Porosity Variogram
Layer 8 (Limestone)



Horizontal Porosity Variogram
Layer 8 (Limestone)



Gaussian Simulation of Porosity



Porosity models for limestone and dolomite were built on a by-layer basis with SGSIM and then put together according to the layer and lithology template

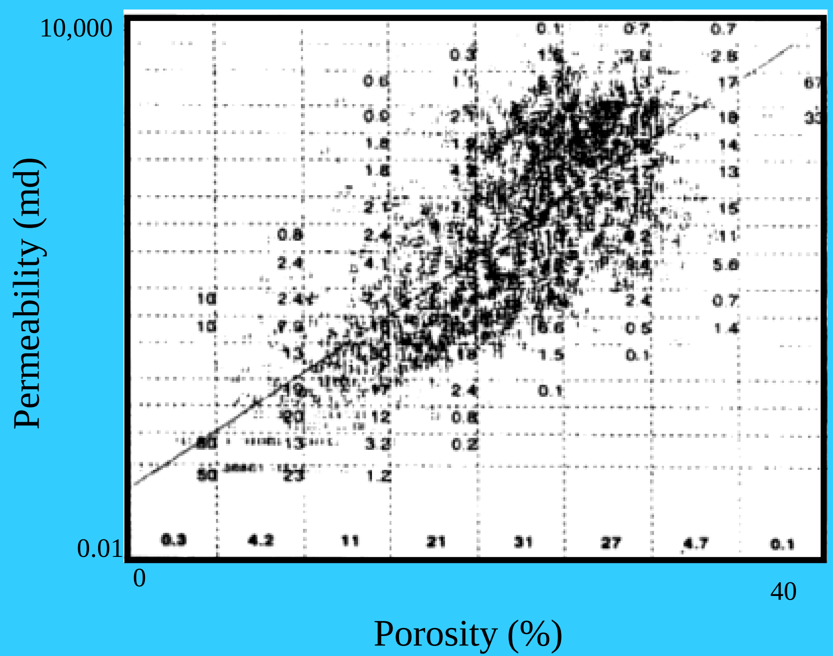
Indicator Simulation of Matrix Permeability

Group 1 - Limestone

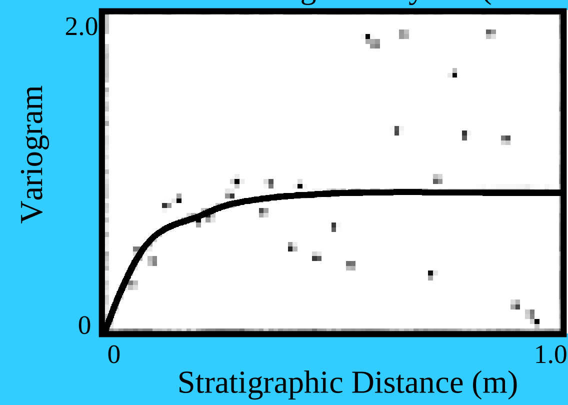
Means:
Porosity = 21.57
Permeability = 295.7

Correlation:
Pearson = 0.73
Spearman = 0.70

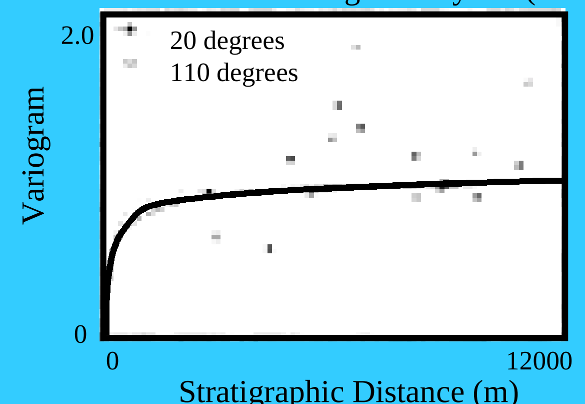
Linear Transform:
Slope = 0.129
Intercept = -1.224



Vertical Matrix k Variogram Layer 5 (Limestone)

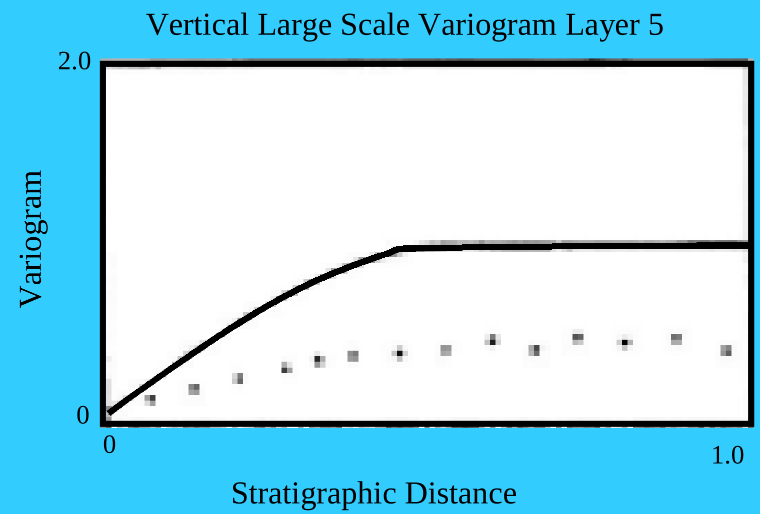


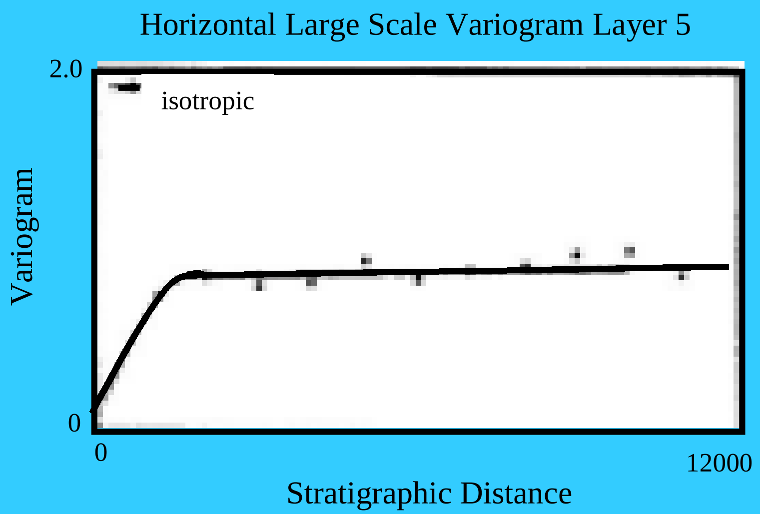
Horizontall Matrix k Variogram Layer 5 (Limestone)



Numbers above x-axis are porosity class percentages
Numbers at corners are porosity/permeability class percentages

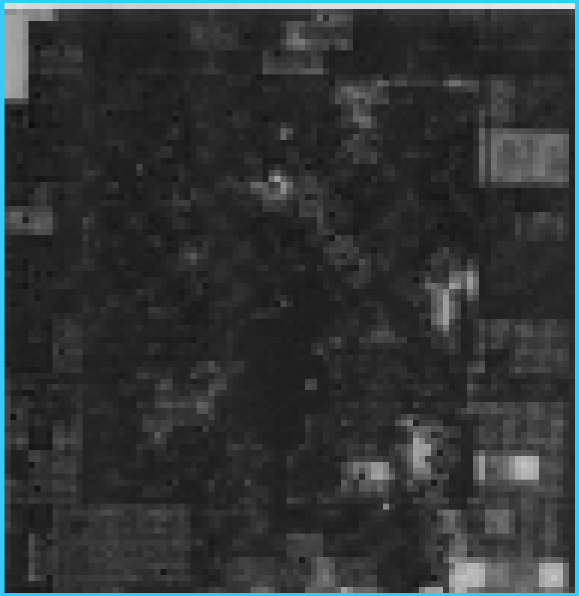
Gaussian Simulation of Large-Scale Permeability





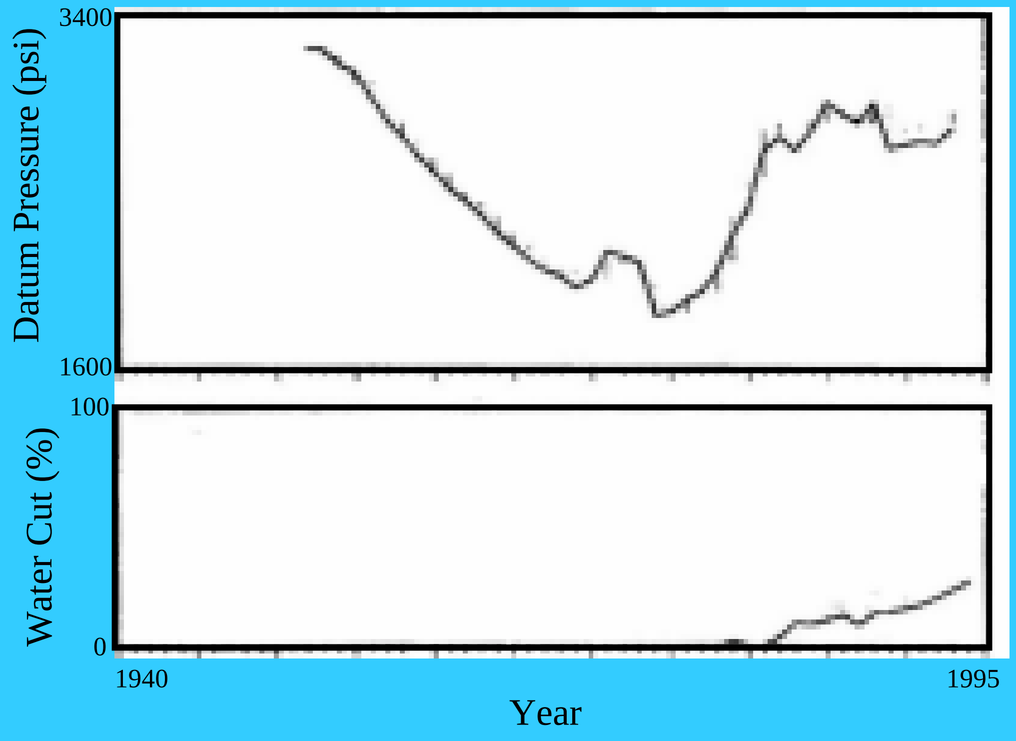
- Matrix permeability at each well location yields a $K{\bullet}h_{matrix}$
- Well test-derived permeability at each well location yields a $K{\bullet}h_{total}$
- Subtraction yields a $K{\bullet}h_{large}$
- Vertical distribution of $K{\bullet}h_{large\ scale}$ on a foot-by-foot basis is done by considering multiple CFM data

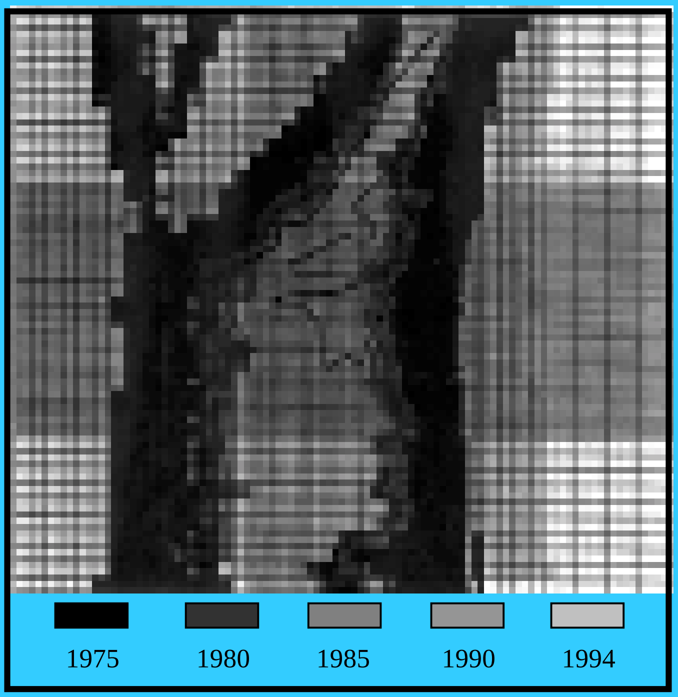
Gaussian Simulation of Large-Scale Permeability



- Large-scale permeability models were built on a by-layer basis with SGSIM
- Matrix permeability and large-scale permeability models were added together to yield a geological model of permeability
- A calibrated power average was considered to scale the geological model to the resolution for flow simulation

Flow Simulation: First History Match





Flow Simulation: Fourth History Match