Pros and Cons of Various Algorithms Used in Stochastic Modeling

Clayton V. Deutsch

School of Mining and Petroleum Engineering

Department of Civil & Environmental Engineering

University of Alberta

April, 1999 • Toulouse France

Pros and Cons

- What I am going to do:
  - walk through reservoir modeling

Basis for Comparison

- Suitability for the problem at hand:
  - heterogeneity modeling accounting for all data
  - uncertainty quantification for decision making
- Proven technology:
  - avoid implementation errors / surprises
  - time to construct / utility in the future
- Simplicity: avoid blunders / reduce time
- Flexibility: all data including future monitoring

Work Flow

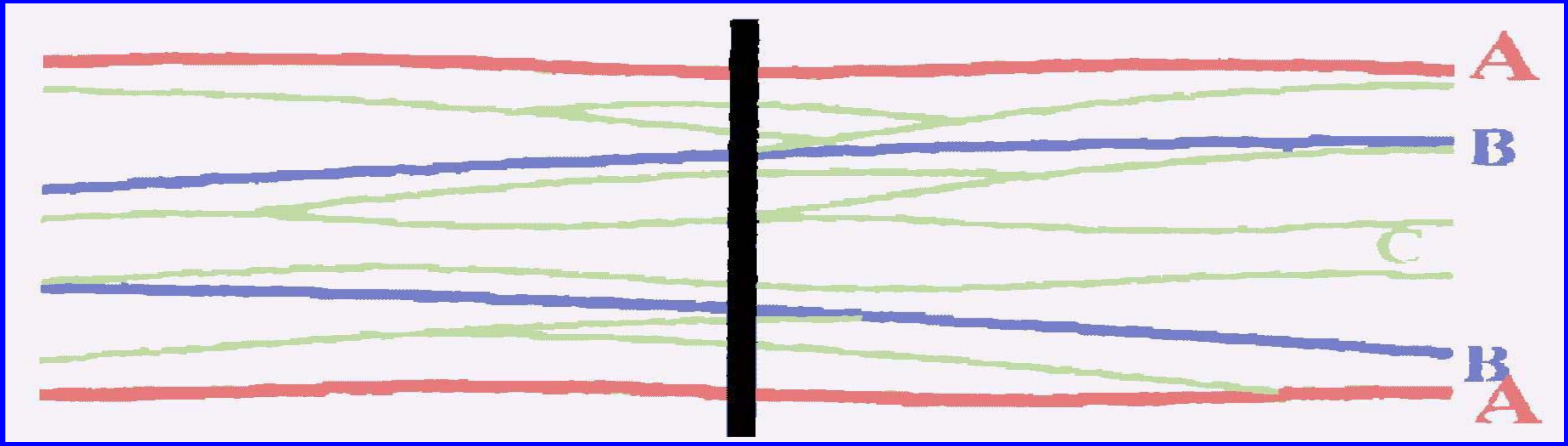
- Sequential Modeling:
  - large scale structure: surfaces / faults
  - stratigraphic surfaces
  - lithofacies
  - porosity / permeability
- Scale up and translation to flow simulation
- Reservoir management decision making

Faults / Large-Scale Topology

- *Mostly* deterministic and outside the main focus of geostatistics
- Stochastic faults with Boolean simulation
  - simulate the geometric position of faults
  - condition to seismic data
  - simulate continuous properties (transmissibility)
- Facet/tetrahydra based tolpology
- Pros and cons: few methods...

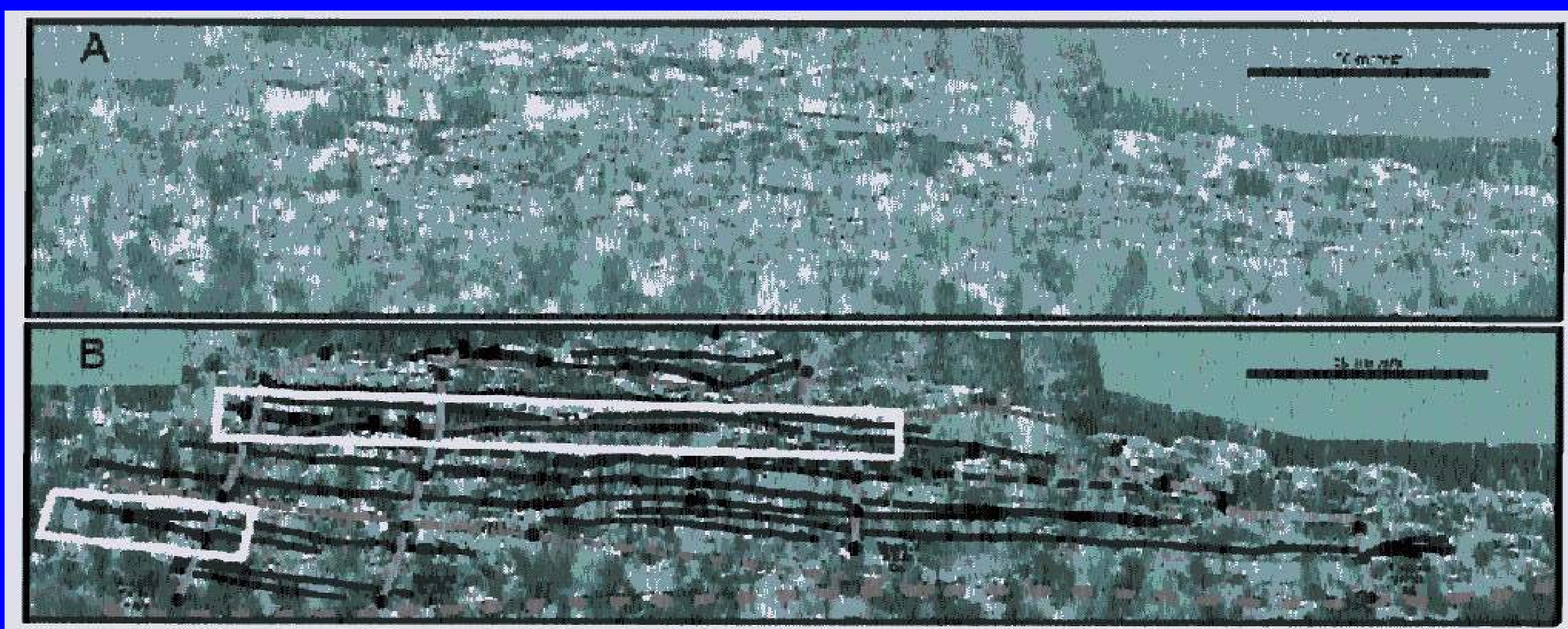
Surface Modeling

- Bounding surfaces provide important controls on facies and trends in petrophysical properties
- More important than facies modeling in many reservoirs

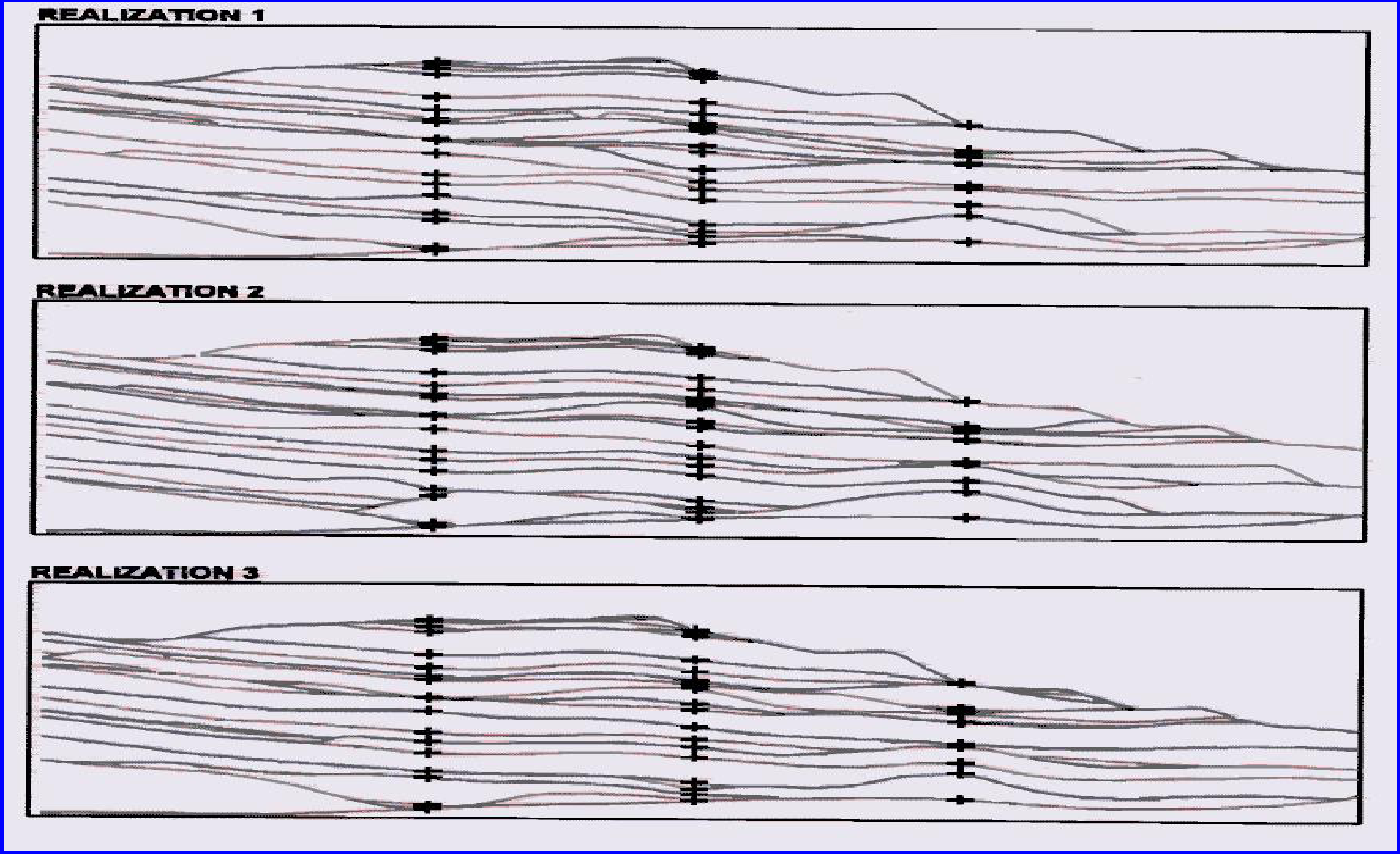


Stochastic Surfaces for Deepwater Systems

- Outcrop studies support "layered" nature of deepwater systems
- Fining upward trend within sediment packages



Surface Modeling Based on Hybrid Boolean / Gaussian Techniques



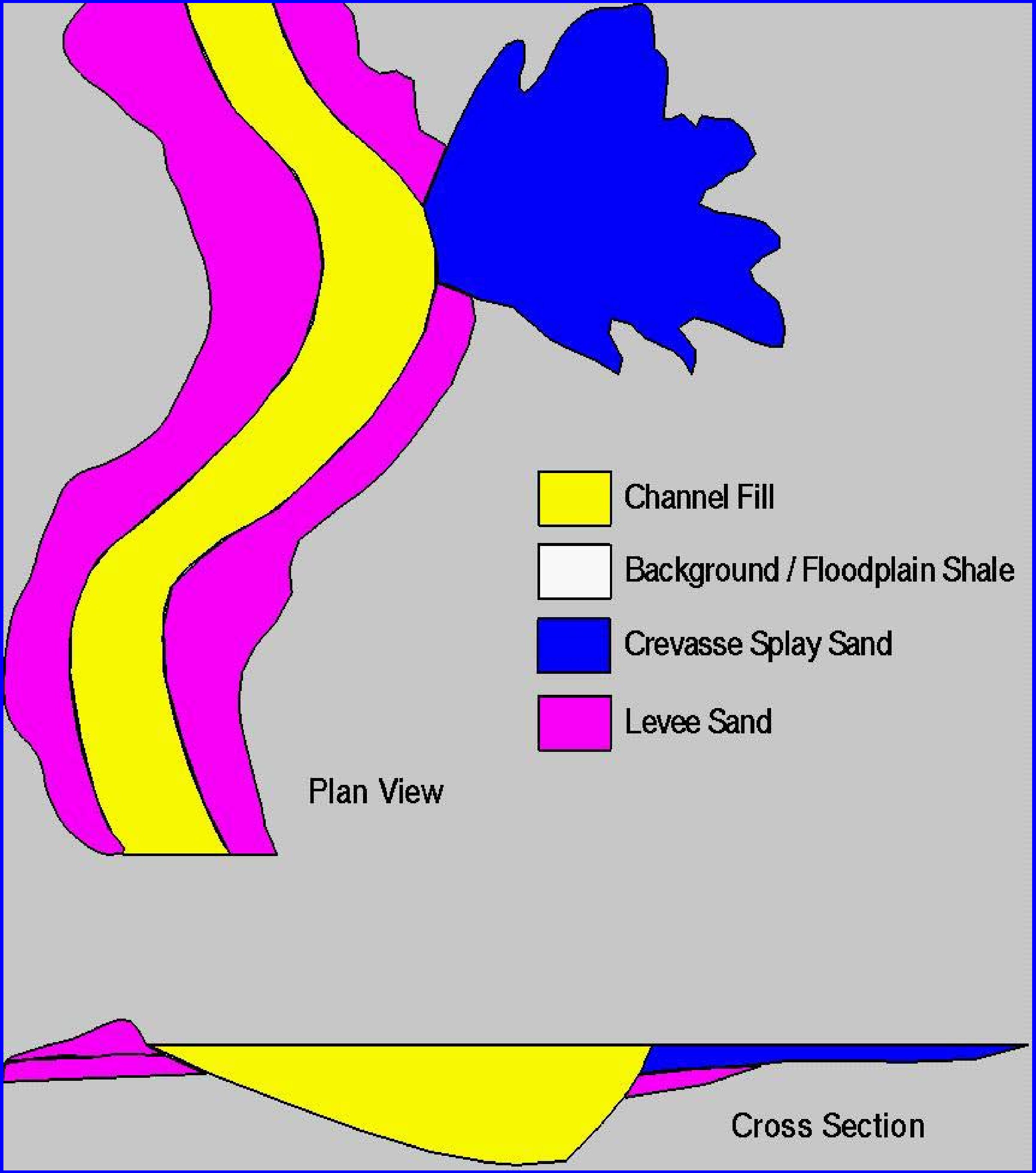
Surface Modeling Pros and Cons

- Volumetric uncertainty (top, OWC…)
- For stratigraphic layering at scales that defy reliable interpretation
- Techniques?
  - Object-based template shape
  - Gaussian deviations from template shape for realism and data conditioning
- Always appropriate for uncertainty quantification and "layered" systems

Lithofacies Modeling

- More techniques to choose from:
  - object-based versus cell-based
  - many different cell-based algorithms
- Cases where object-based are clearly better:
  - deposition led to “nice” geometric shapes
  - low to intermediate net-to-gross systems
- Cases where cell-based are clearly better:
  - strong diagenetic effects mask “shapes”
  - high net-to-gross systems

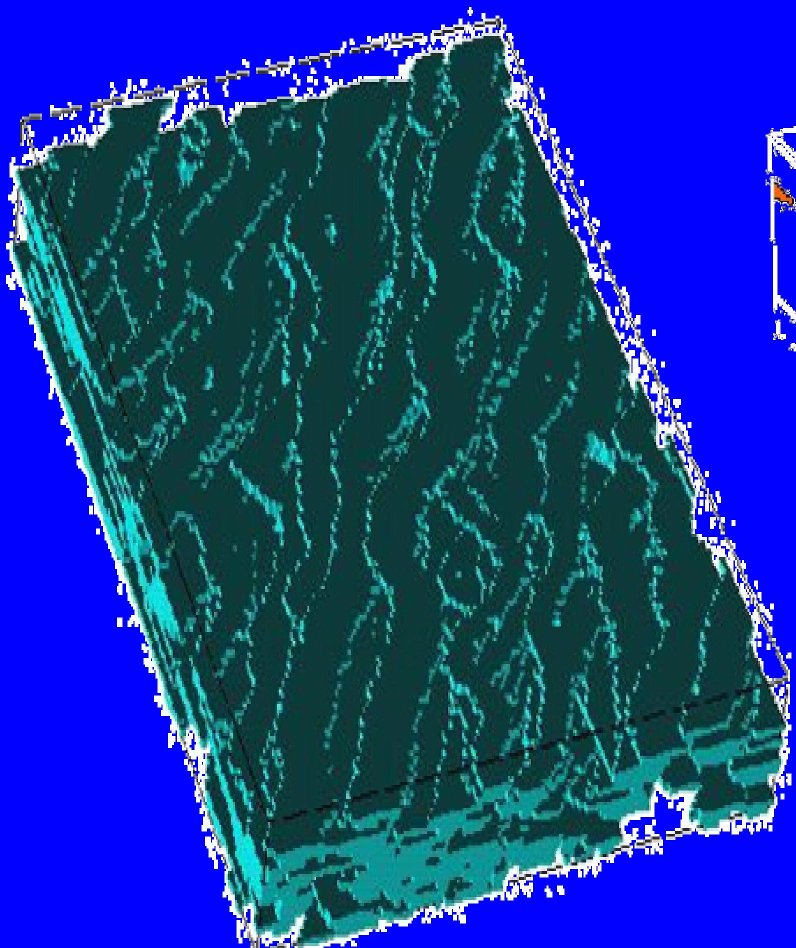
Object Parameterization

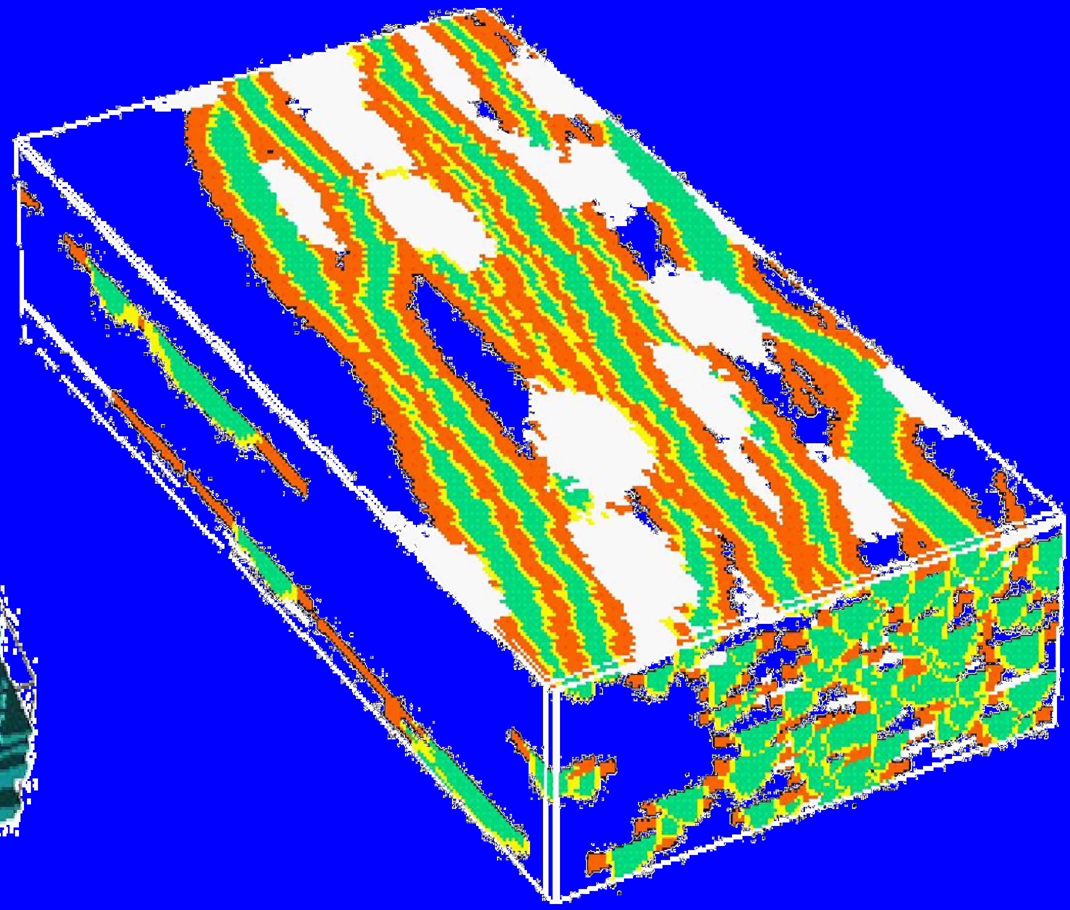


Basis to Compare Object-Based Techniques

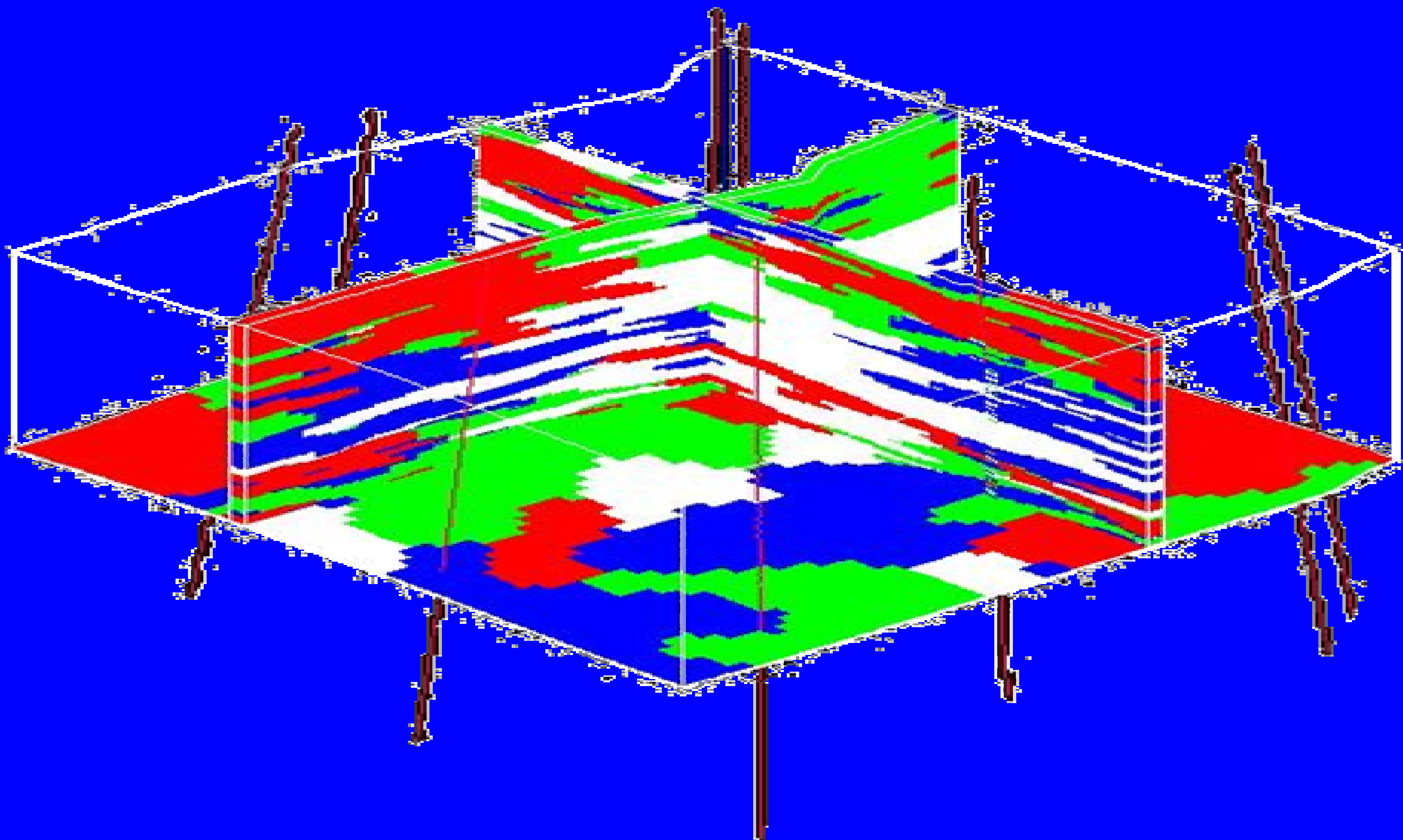
- Geologically realistic parameterization
- Accessible parameters for shape and positioning
- Flexibility to integrate other data types
- Free of artifacts from positioning algorithm
- Fast enough to allow sensitivity studies…
- Integrated petrophysical property modeling (correct continuity and trends)

Some Examples





Cell Based



Cell-Based Lithofacies Modeling

- Variogram / two-point stats. for spatial control
- Reliable inference of multiple point statistics has limited application in that area
- Many different techniques:
  - sequential indicator methods
  - truncated (pluri)Gaussian methods
  - iterative methods
- Let’s look at some pros and cons of the different methods

Sequential Indicator Simulation

- Pros:
  - straightforward spatial control of lithofacies
  - easy integration of seismic data
  - fast / robust
- Cons:
  - simplistic linear features that may be considered non-geological
  - little control on lithofacies patterns due to awkward calculation and use of cross variograms

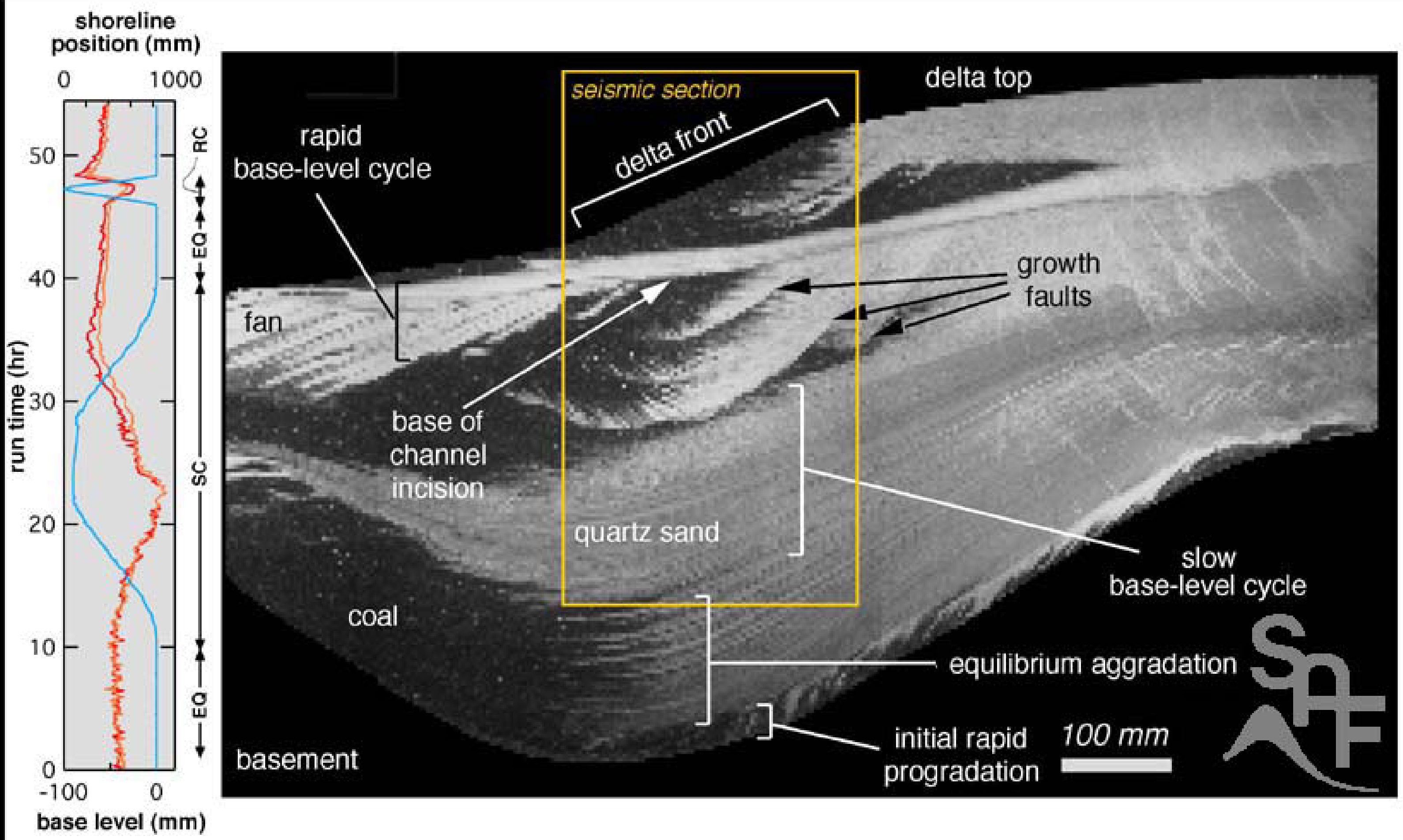
Truncated Gaussian Methods

- Pros:
  - straightforward spatial control of different facies (particularly “nested” or “ordered” lithofacies)
  - easy integration of seismic data
  - fast / robust
- Cons:
  - linear features may be considered non-geological
  - awkward inverse problem for pluriGaussian approach

Iterative Methods for Lithofacies

- Numerical Rocks / Simulated Annealing
- Pros:
  - flexible data integration
  - arbitrary spatial control with any “order” statistics
- Cons:
  - “delicate adjustment of many tuning parameters”
  - numerical artifacts
  - CPU requirements

Non-Linear Features



Labelled photographic panel of the deposit produced in the prototype XS basin run. Transport was from right to left. Light tones are quartz sand, dark tones crushed coal. The rectange indicates the area imaged with synthetic seismic techniques in the adjoining figure. Base-level history is shown in the panel at left (blue line), with the slow and rapid base-level cycles (SC and RC respectively) and periods of equilibrium (EQ) marked. All other variables were held constant. Shoreline position measured on longitudinal transects within and outside of the rapid-cycle incision is also shown at left (red and orange lines respectively).

Porosity Permeability Modeling

- Many techniques to honor a histogram and variogram, which are adequate once facies…
- Gaussian techniques (matrix, sequential, spectral, …) equally appropriate
- Indicator techniques that provide advantages of (1) data coding, (2) continuity of extremes
- Need to handle soft data at different scales (seismic and production data) and hard data at a much reduced scale

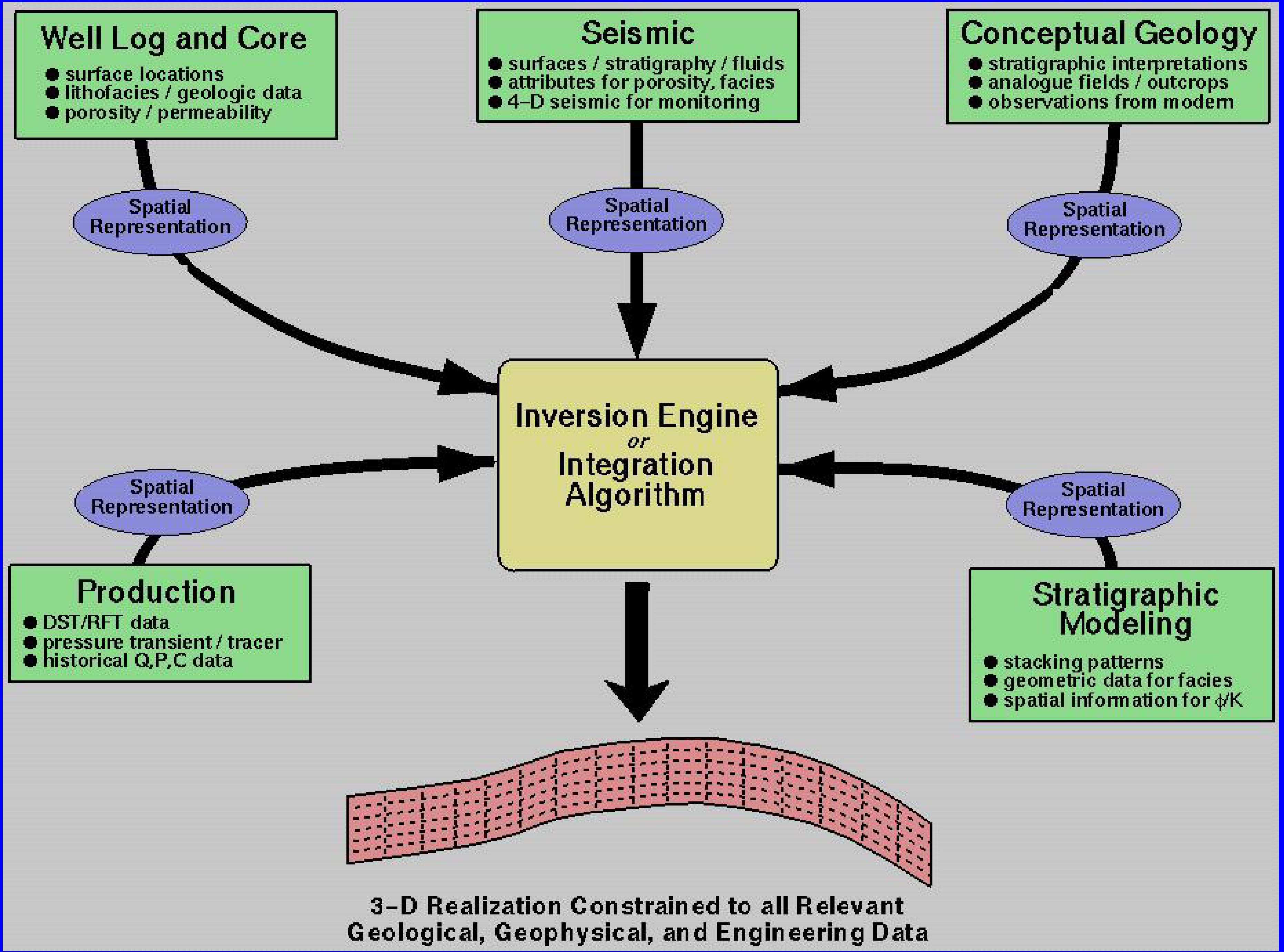
Scaling and Translation to Flow Simulation

- Flow-based scale-up is routinely applied
- Minimize artifacts due to boundary conditions
- Scale-up within "homogeneous" lithofacies units
- Align grid with heterogeneity and flow patterns
- Local grid refinement near wells
- Perform runs to see effect of grid size

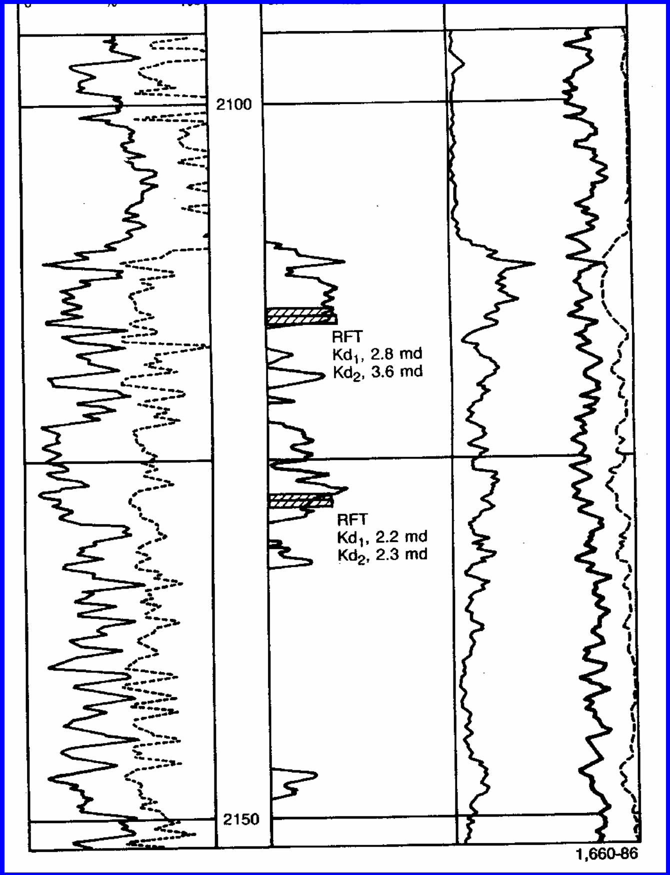
Not Mainstream Geostatistics

Reservoir Management Decision Making

- Once again: ***Not Mainstream Geostatistics***
- Geostatisticians must provide results that lead to improved decision making
- Rank realizations to limit subsequent CPU effort
- Decision making in face of uncertainty
  - exploration drilling / well site selection
  - development planning: wells, maintenance,…
  - IOR decisions, scenario ranking

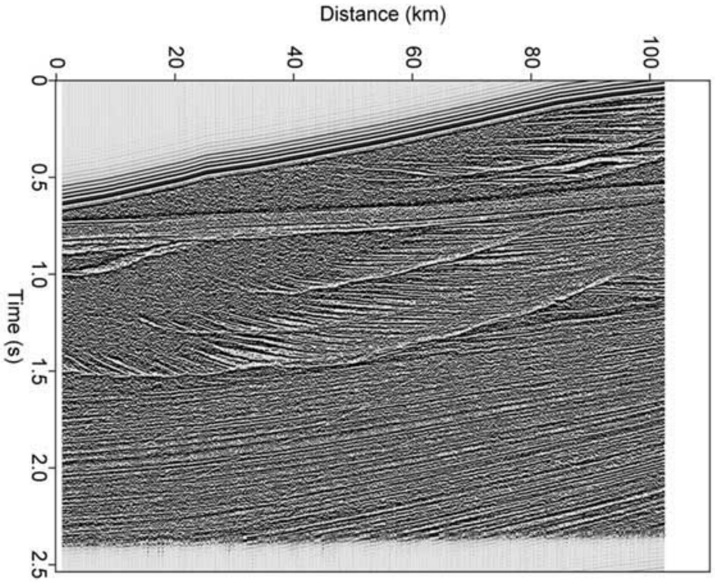

Well Log and Core
surface locations
lithofacies / geologic data
porosity / permeability
Seismic
surfaces / stratigraphy / fluids
attributes for porosity, facies
4-D seismic for monitoring
Conceptual Geology
stratigraphic interpretations
analogue fields / outcrops
observations from modern
Spatial Representation
Spatial Representation
Spatial Representation
Inversion Engine
or
Integration Algorithm
Spatial Representation
Spatial Representation
Production
DST/RFT data
pressure transient / tracer
historical Q,P,C data
Stratigraphic Modeling
stacking patterns
geometric data for facies
spatial information for ϕ/K
3-D Realization Constrained to all Relevant Geological, Geophysical, and Engineering Data

Well Log and Core



- Surfaces, lithofacies, porosity, permeability
- Handled by virtually all algorithms
- Outstanding issues:
  - scaling between core/log/cell
  - uncertainty in petrophysics
  - permeability values
  - object-based modeling

Seismic Data

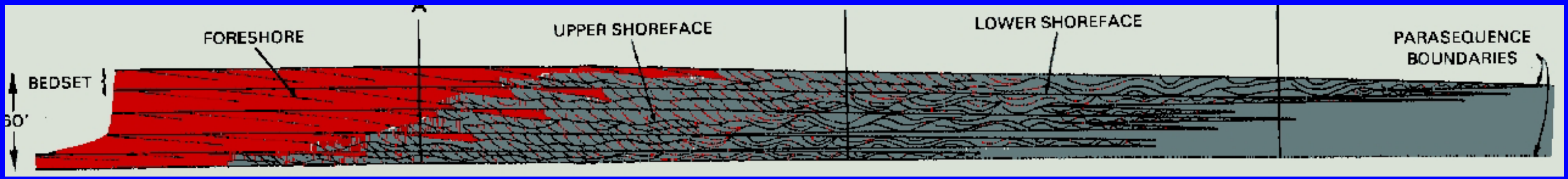


Time and distance scale are arbitrary

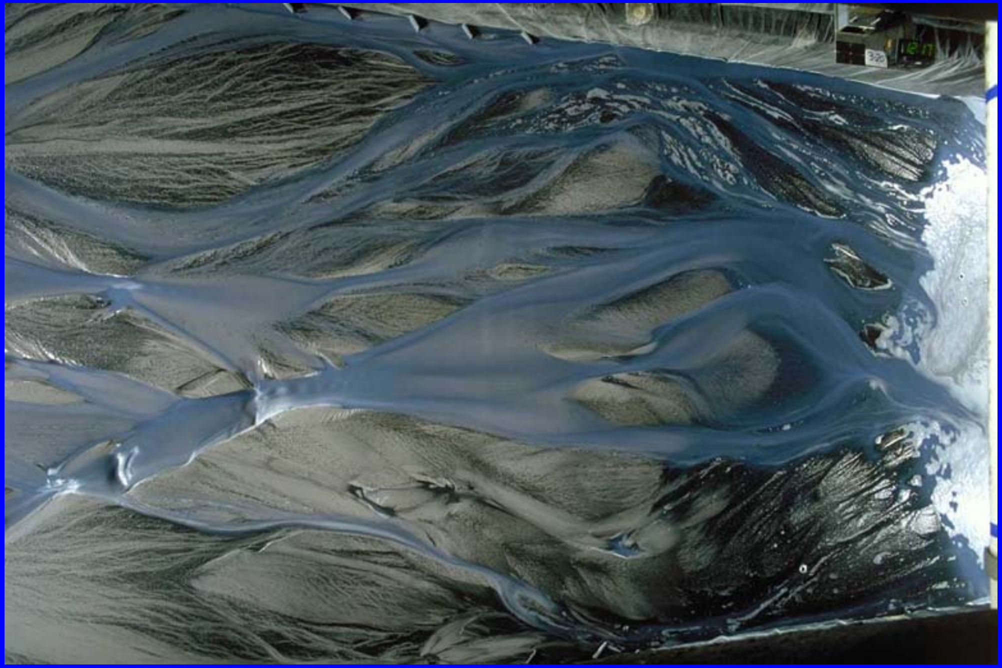
- Surfaces, stratigraphy, attributes, 4-D monitoring
- Handled reasonably well
- Outstanding issues:
  - – scale and uncertainty
  - – information from 4-D
  - – actual seismic data versus interpreted attribute

Conceptual Geology

- Stratigraphic interpretations
- Understanding of stacking patterns, areal trends, relationships of facies,…
- Most geostatistical models would be found lacking by a geological expert
- Many outstanding issues related to complex geometry, continuity, scaling... $\rightarrow$ *quantification*

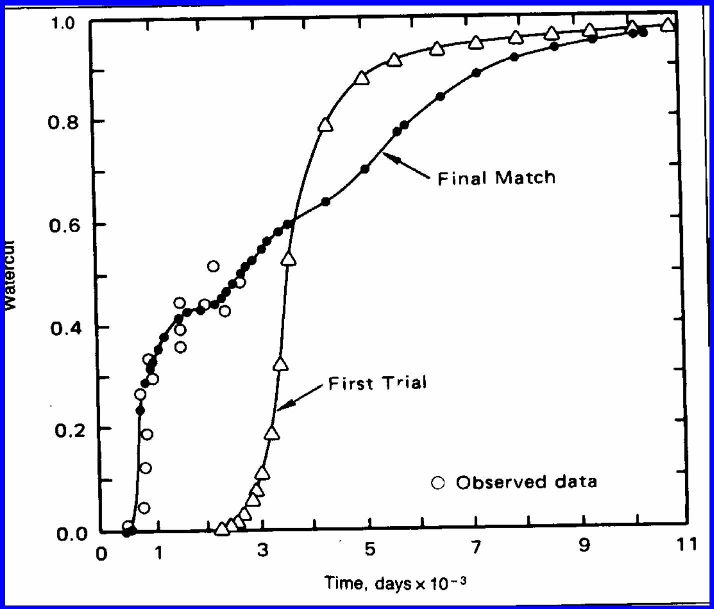


Forward Modeling



- Architecture of sediment structures
- "Correct" physics
- Not well handled
- Outstanding issues:
  - scaling of results
  - reservoir-specific results…
  - geostat. techniques

Production Data



- Historical production data, DST, RFT, tracer, well test
- Some tools to *extract spatial constraints*
- Increased use of streamlines
- Outstanding Issues:
  - 3-D multiphase data with changing well conditions
  - integration with other data types

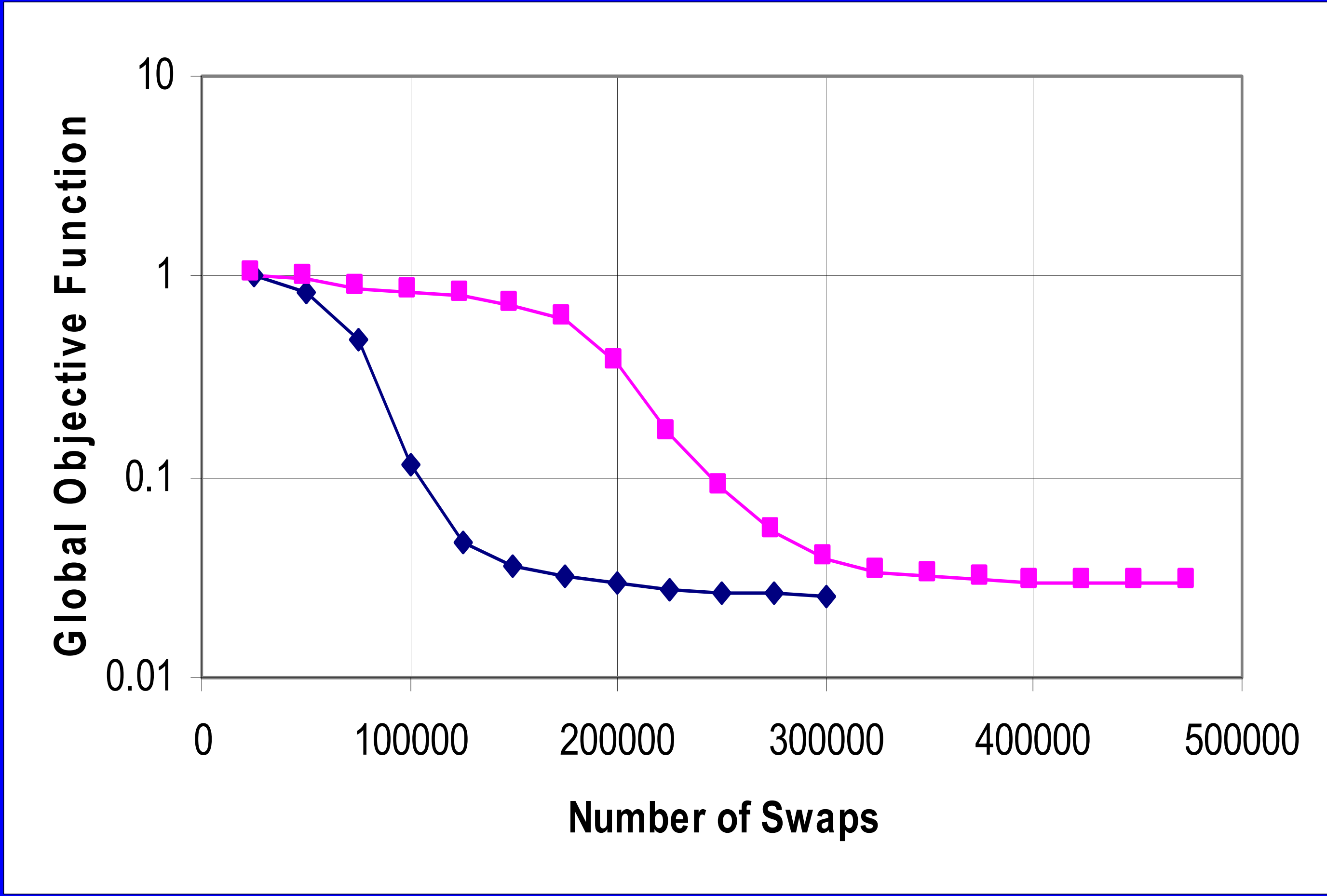
Pros and Cons: Some Truisms

- Practice / real life application quickly separates those methods with more “pros” than “cons”
- Theoretical “pros” do not lead to practical ones
- Practical acceptance will ultimately lead to theoretical justification
- Good software will add considerable strength to any algorithm
- Simple solutions with accessible input data are always preferred

Future Research and Development

- Object-based models for non-fluvial settings
- Techniques to account for forward modeling:
  - surface-based modeling
  - rule induction technology
  - multiple point statistics
- Rigorous accounting of volumetric support
- Practical production (dynamic) data integration
- Integration of *all* data by "inversion"
- Transfer of uncertainty to decision making

Potential for CPU Improvements



Critical Temperature in Simulated Annealing