Reservoir Simulation Overview

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Petroleum Reserve Estimation, Production, and Production Sharing Contract (PSC) Short Course

Bangladesh University of Engineering and Technology

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Overview Objectives

- Define reservoir simulation and it's benefits
- Prepare business case for reservoir simulation
- Review key uncertainties associated with reservoir simulation.
- Identify the different modeling methods available
- Describe the key steps in a simulation study

What is Simulation?

As applied to petroleum reservoirs, simulation can be stated as:

The process of mimicking or inferring the

behavior of fluid flow in a

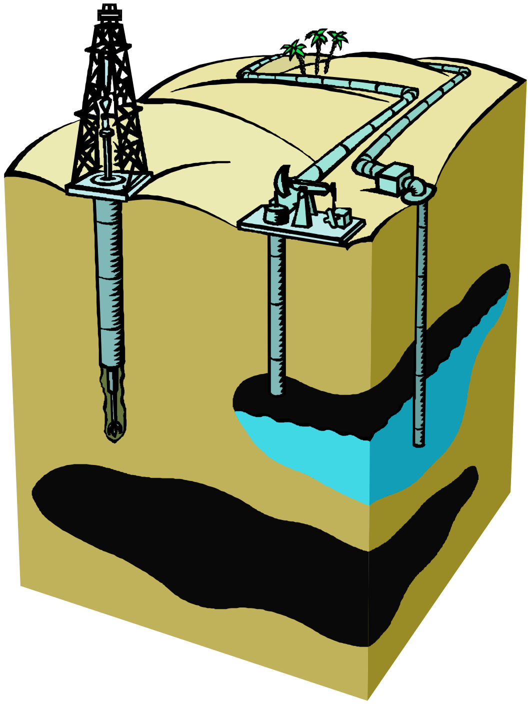
petroleum reservoir system

through the use of either

physical or mathematical models

What is Simulation?

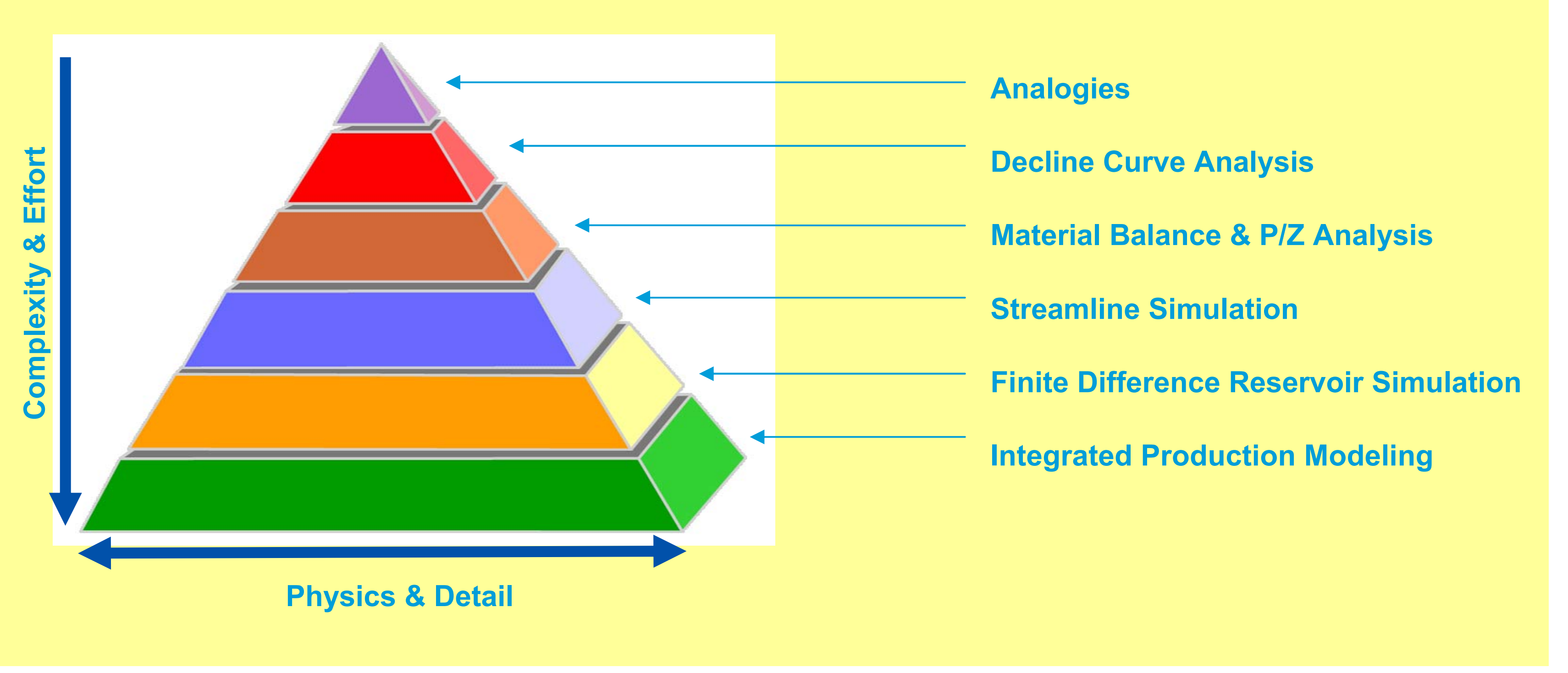
As used here, the words *petroleum reservoir system* include the reservoir rock and fluids, aquifer, and the surface and subsurface facilities.



Business Reasons for Using Reservoir Simulation

- Economics and timing of investments
- Credibility and Reliability
- Decision Making
- Arbitration, Unitization, & Regulation
- Performance Monitoring

Modeling Methods



- Any problem is solvable if you can make ***assumptions*** - the key is determining the ***right*** assumptions.
- Not every question demands in-depth modeling of every detail.

Modeling Methods
Data Considered by Method

What are the assumptions for each method?

	Decline Curve	Material Balance	Numerical Simulation
Field Measurements			
Well Pressures		●	●
Oil, Water, Gas Production	●	●	●
Production Logs			●
Well Tests			●
Reservoir Description			
Geometry			●
Petrophysical Properties			●
OWC's, GOC's			●
Lab Measurements			
PVT Properties		●	●
Relative Permeability			●
Capillary Pressure			●
Well Descriptions			
Location			●
Completion Interval			●
Completion Changes			●
Stimulations			●

Modeling Methods

All mathematical techniques are simply an application of the three fundamental equations of reservoir engineering

Darcy's Law

+

Material Balance Equation

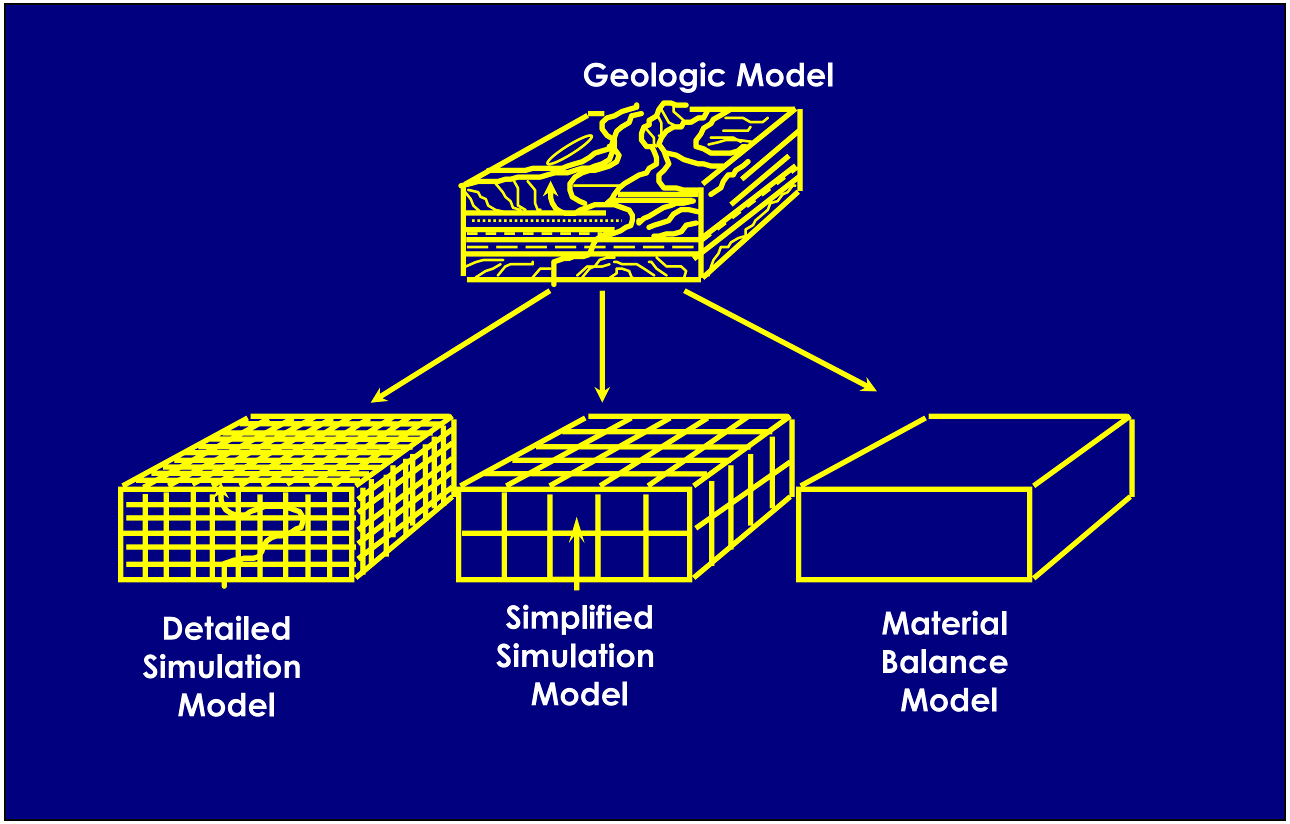
+

Fluid Properties (PVT or EOS)

with varying boundary conditions

Modeling Methods
Finite Difference Process

Divide the reservoir into numerous blocks and represents it with a mesh of points or grid blocks.

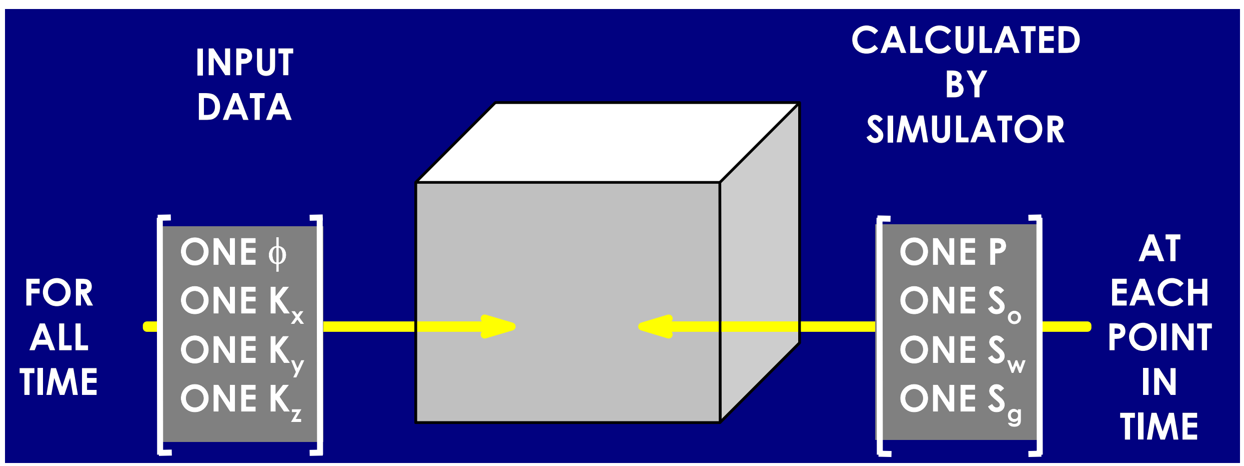


Modeling Methods
Finite Difference 3 Step Process

Solve mathematical equations for each cell by numerical methods to obtain pressure, production and saturation changes with time.

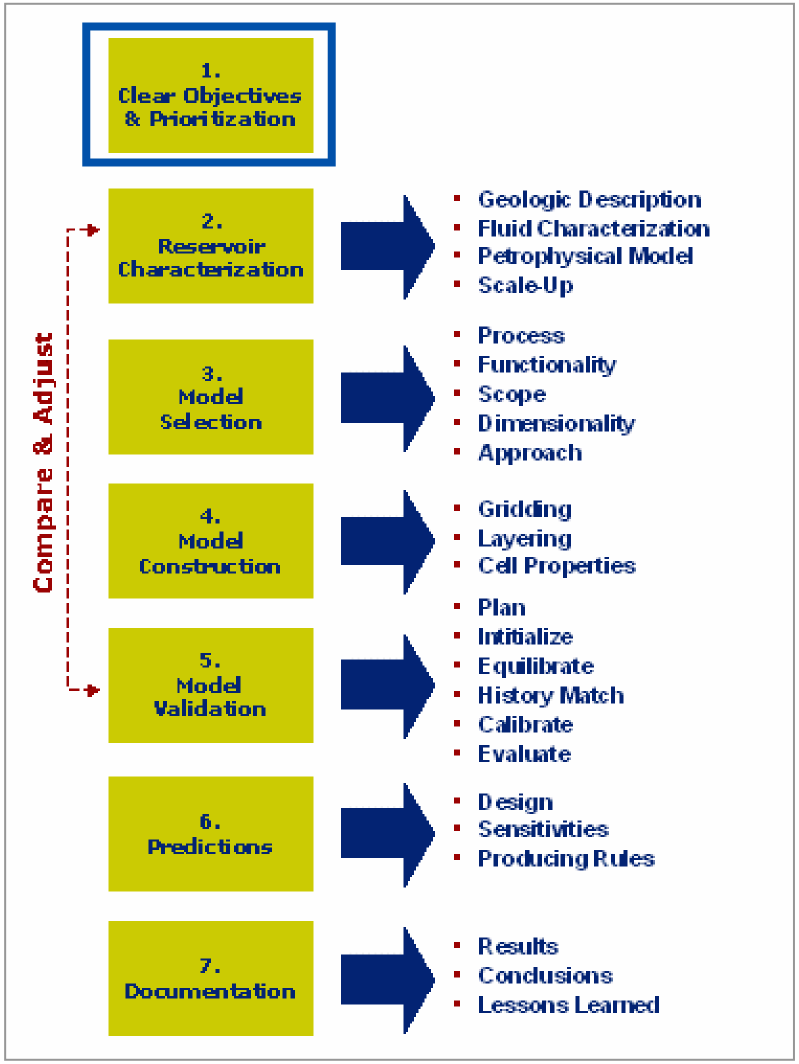
The Diffusivity Equation (Single Phase, 1-D Flow)

$$\frac{k}{\mu}\frac{\partial^2 P}{\partial x^2} = \phi c \frac{\partial P}{\partial t}$$



Accuracy of data input → Impacts accuracy of simulator calculations

Key Steps in a Simulation Study



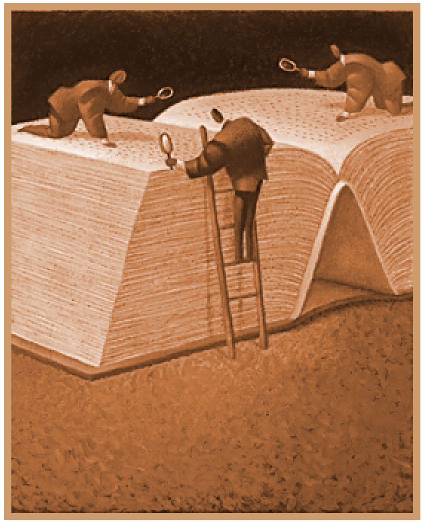
Pre-planning the Reservoir Simulation Study

Considerations:

- Objectives of the study
- Assess uncertainties
- Data requirements and availability
- Modeling approach
- Limitations of proposed procedures
- Resources
  - Project budget – should be related to decisions required
  - Time available
  - Hardware: PC, Workstation, , supercomputer, cluster
  - Software: Commercial (Eclipse®, VIP®…), in-house (such as CHEARS®)

Sources of Uncertainty in Simulation

Data Quality
& Quantity



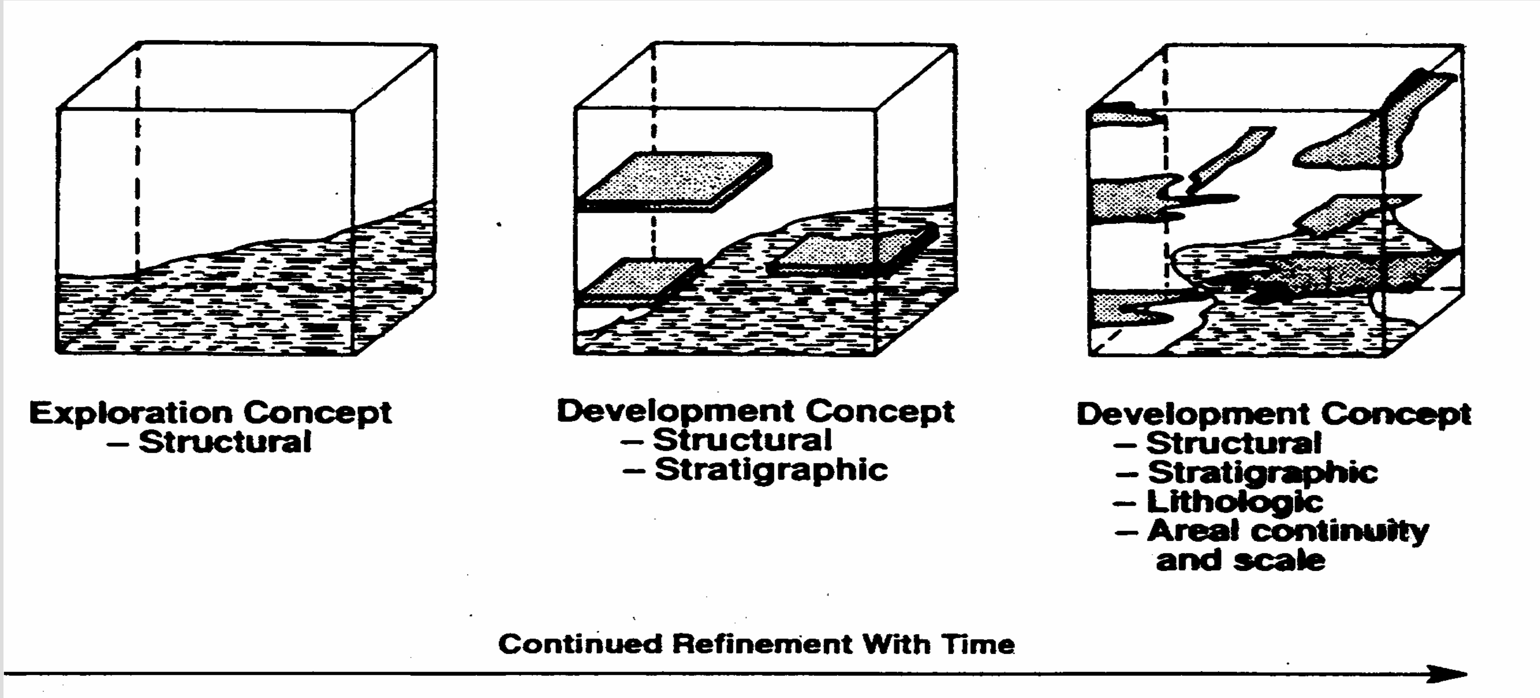
Geology

Mathematical

Scale-Up

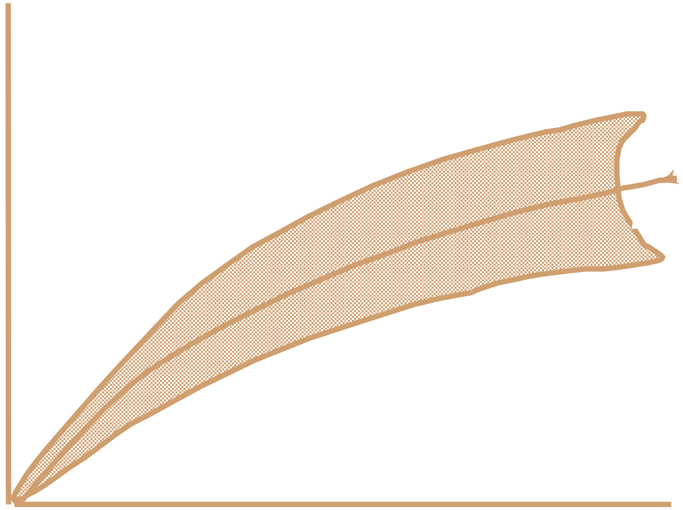
Sources of Uncertainty
Geologic Description

Generally the most uncertain aspect.



Sources of Uncertainty

- Results should carry a "band of uncertainty"
- Models are often asked to provide forecasts beyond the accuracy of the field data
- Worsened by lack of geologic & engineering control



Step 1 – Set Clear Objectives & Priorities

Examples of Reservoir Study Goals

Typical Goals for New Fields:

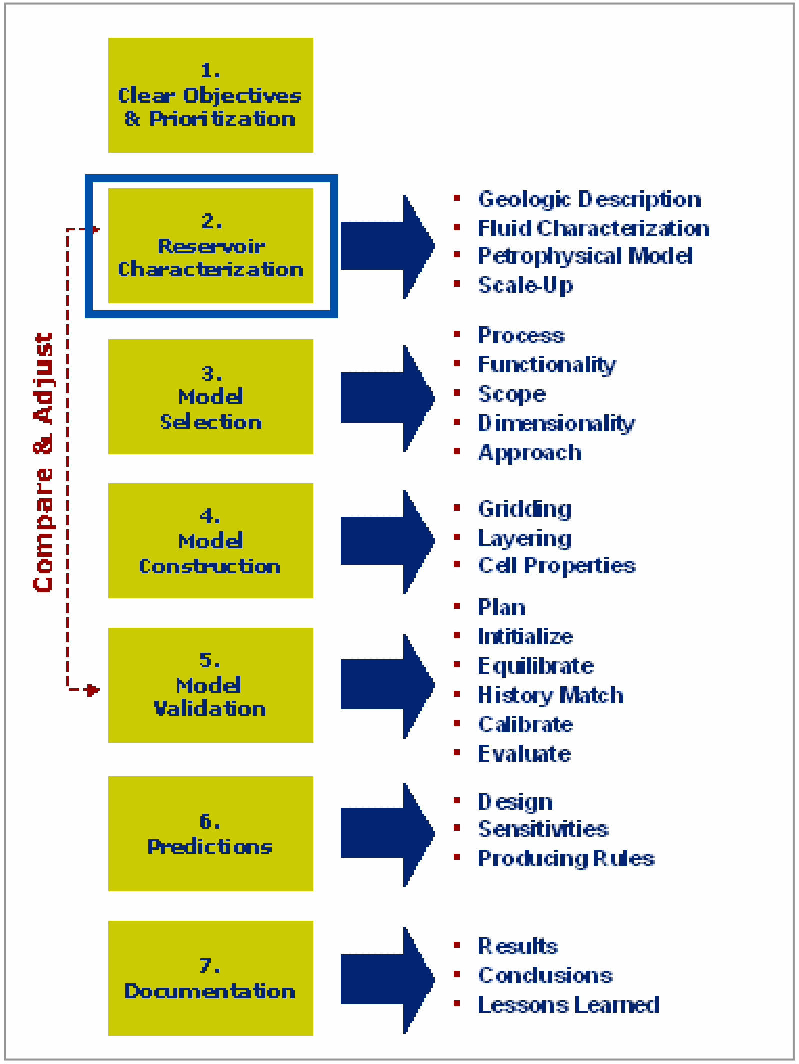
- Define reservoir's internal & external boundaries
- Define reservoir pay, volume, & reserves
- Determine optimum number, location, & configuration of wells
- Optimize timing and sizing of facilities
- Select optimum recovery process
- Estimate potential recovery performance
- Anticipate future produced fluid & operational changes
- Determine critical gas and water coning rates

Step 1 – Set Clear Objectives & Priorities
Examples of Reservoir Study Goals

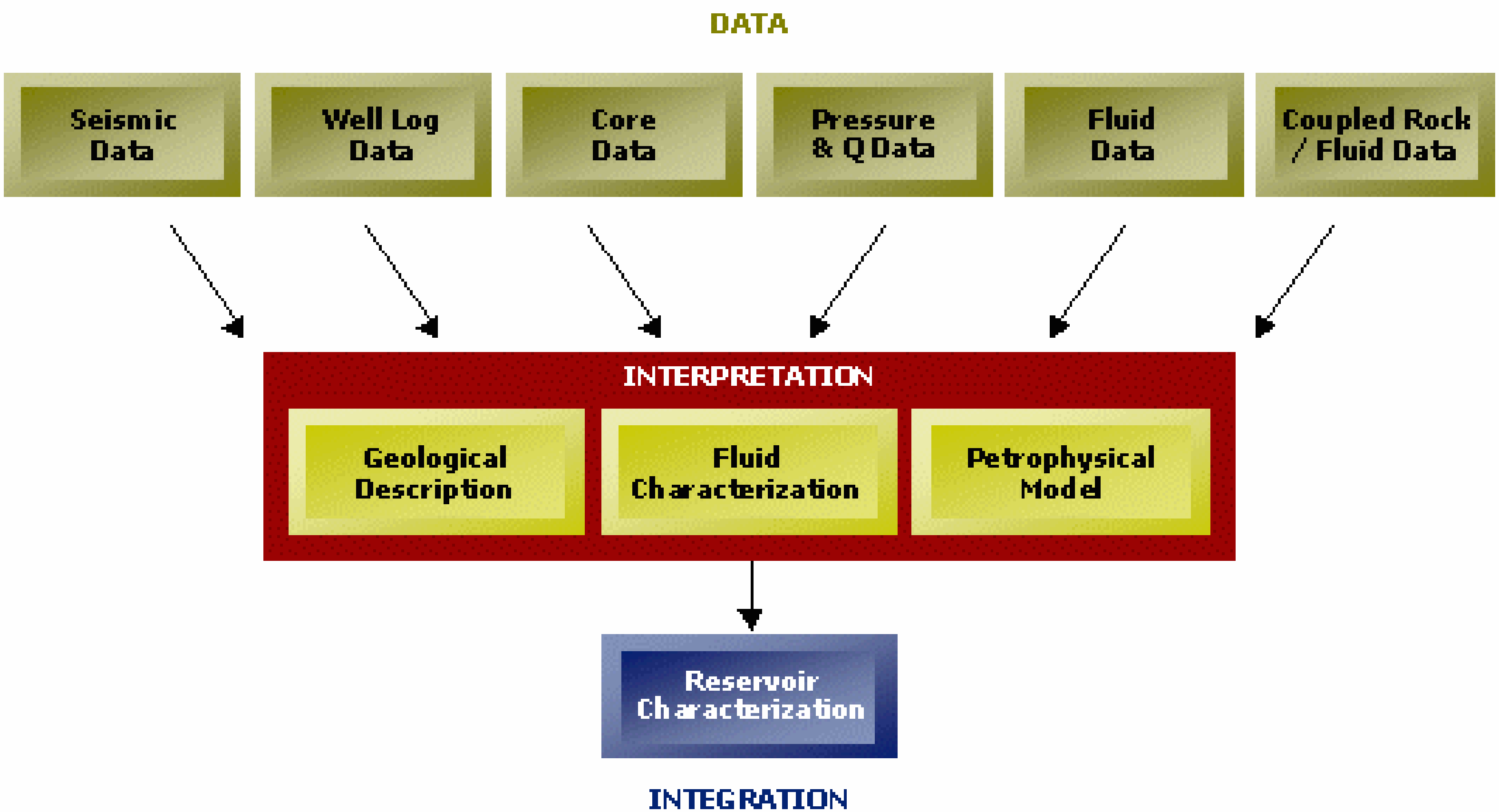
Typical Goals for Mature Fields:

- Monitor fluid contact movement
- Evaluate productivity degradation
- Evaluate historical reservoir performance. Determine why performance did not match predicted recovery
- Determine source of produced water and/or gas. Identify wells with workover potential
- Monitor reservoir sweep to locate by-passed oil. Specify infill drilling requirements
- Estimate benefits of secondary recovery or EOR
- Determine connectivity between multiple reservoirs
- Quantify lease-line migration

Key Steps in a Simulation Study

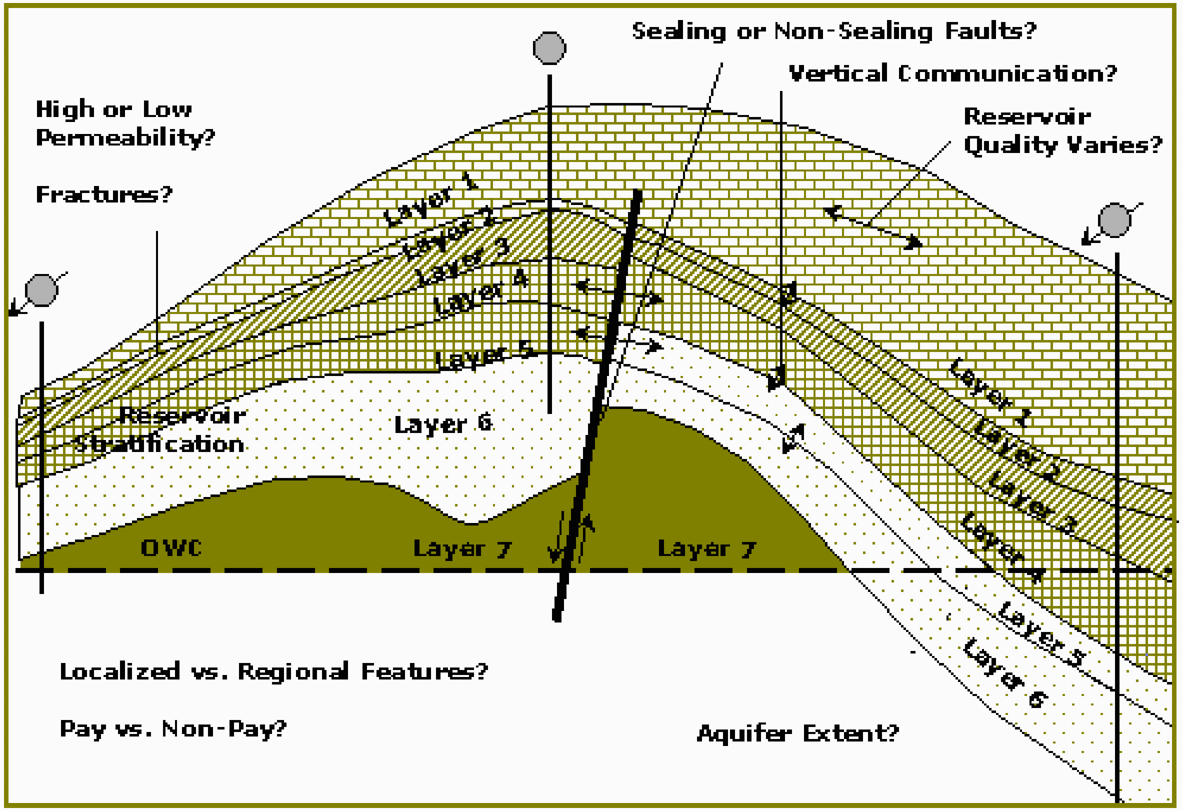


Step 2 – Characterize the Reservoir
Three Inter-Dependent Components



Step 2 – Characterize the Reservoir
Geological Description

A geological description must identify the key factors which affect flow through the reservoir:



Fluid Characterization

Fluid characterization defines the physical properties of the reservoir fluid mixture, and how they vary with changes in pressure, temperature and volume.

Steps to characterize the reservoir fluids:

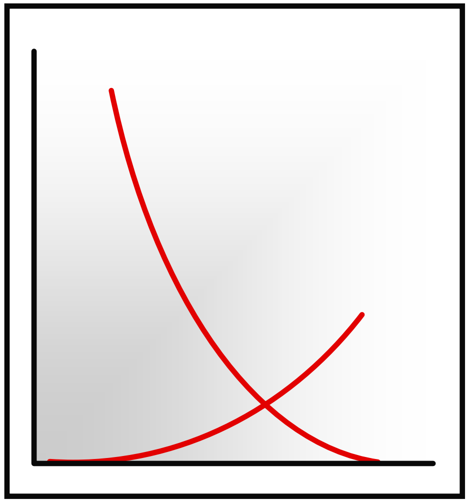
- Classify the fluid type
- Determine reservoir fluid properties
- Describe reservoir production mechanisms

Step 2 – Characterize the Reservoir
Petrophysical Model

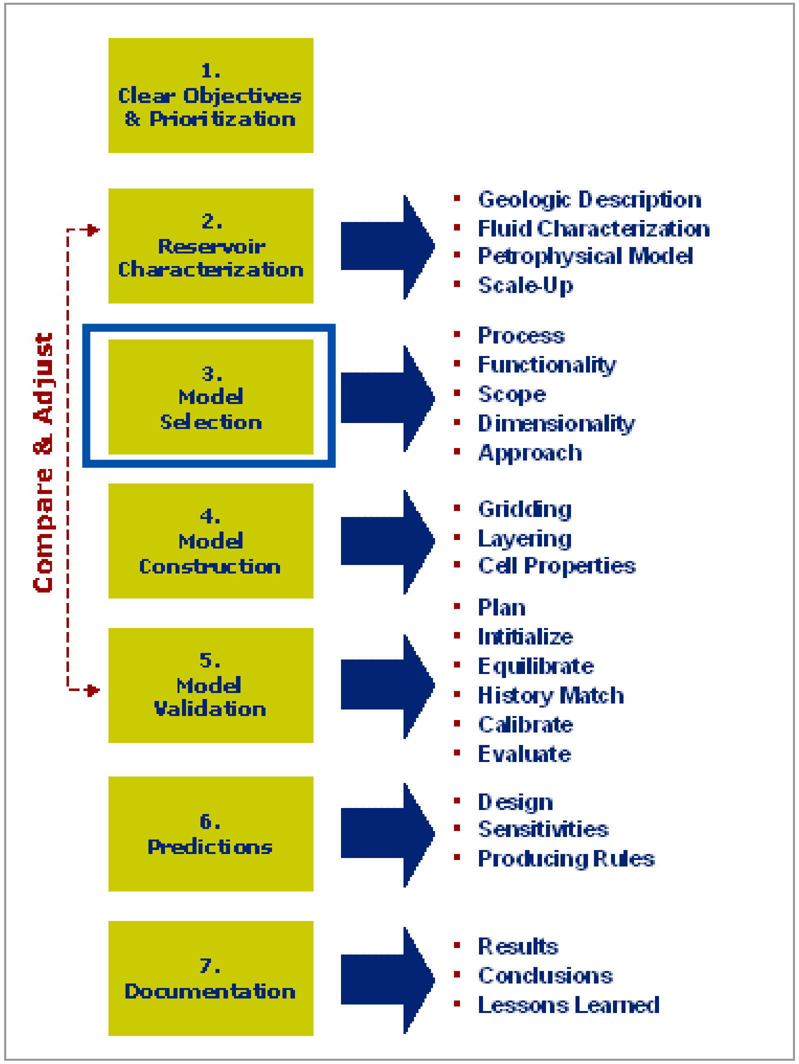
The petrophysical model defines where the volumes of oil, water and gas are located in the reservoir, as well as how fluids behave in the presence of the rock.

To define the petrophysical model of the reservoir, you must determine:

- Rock Wettability
- Capillary Pressure
- Relative Permeability
- Residual Oil Saturation
- Fluid Contacts



Key Steps in a Simulation Study



Step 3 –Aspects of Model

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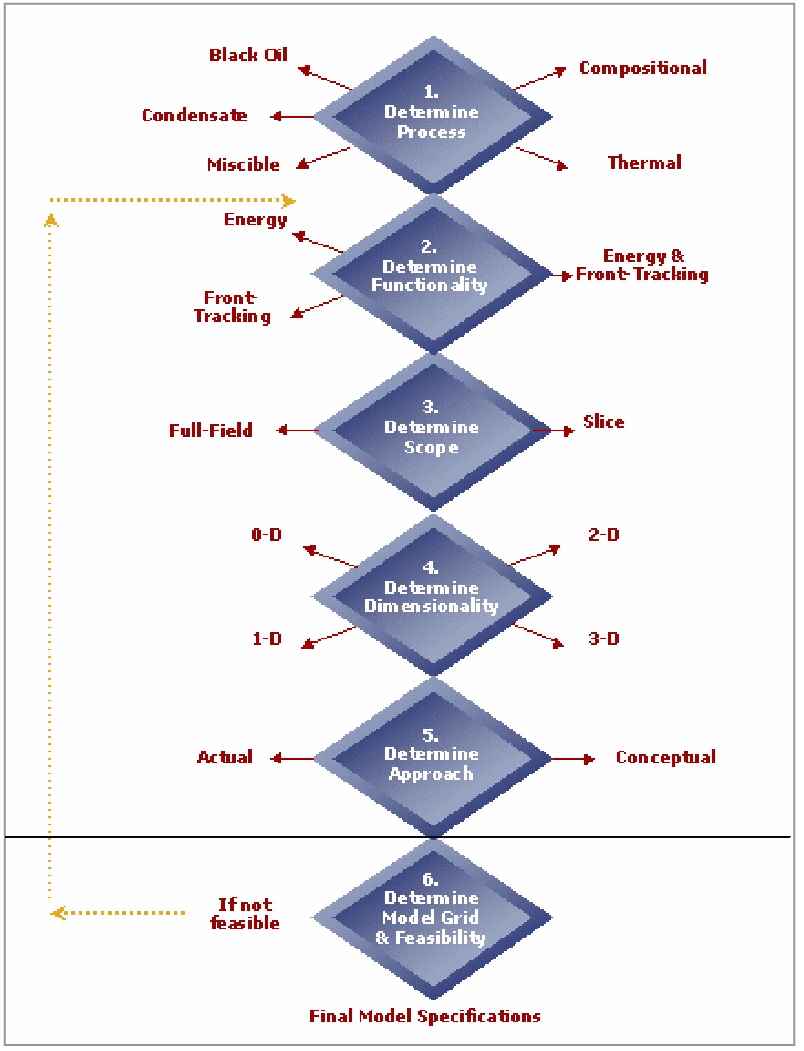
1. Process
2. Functionality
3. Scope
4. Dimensionality
5. Approach



Step 3 – Select the Model

Determine the Process

- Black Oil
- Condensate
- Miscible
- Compositional
- Thermal

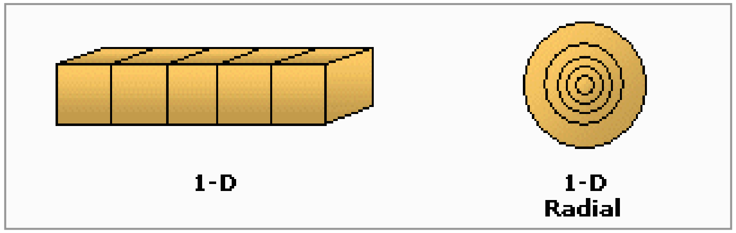
Step 3 – Select the Model

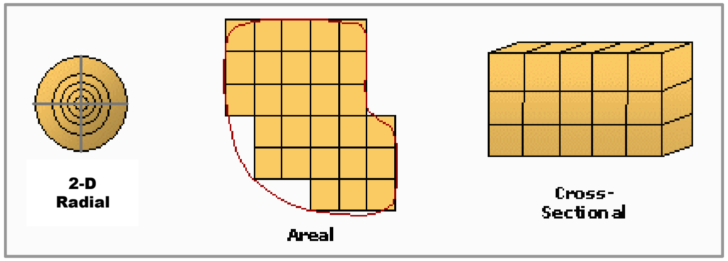
Determine the Functionality

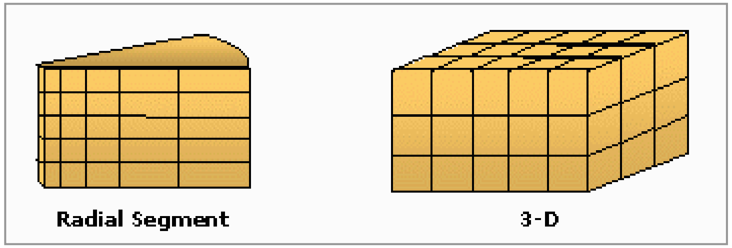
Type of Model	Examples
Energy	▪ Estimation of OOIP/OGIP ▪ Material balance computations
Front-tracking	▪ Determination of critical well coning rates ▪ Pattern-flood studies ▪ Workover and recompletion evaluation studies ▪ Development of interblock relative-permeability curves for coarse-grid models
Energy and Front-tracking	▪ Pressure and production forecasts ▪ Determination of drilling, workover and artificial-lift requirements ▪ Evaluation of primary and secondary recovery programs and field development plans

Step 3 – Select the Model
Determine the Dimensionality

- Use 1D models for linear or radial flow in only one direction
- Use 2D models for linear or radial flow in two directions: Radial, areal, cross-sectional
- Use 3D models for situations for linear or radial flow in three directions: Pattern element, segment, full-field

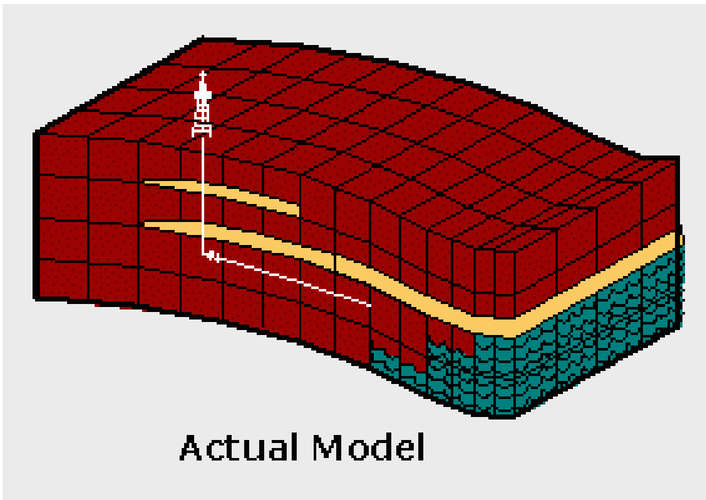




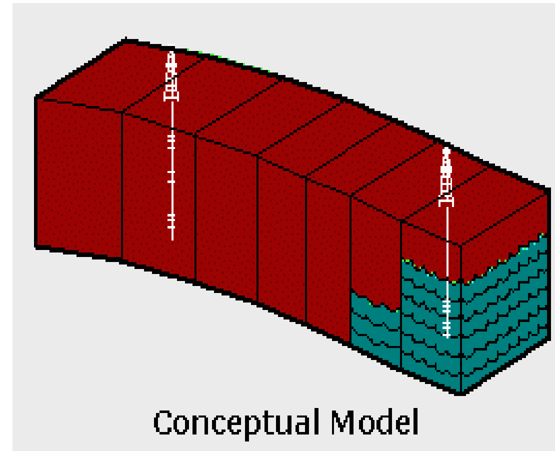


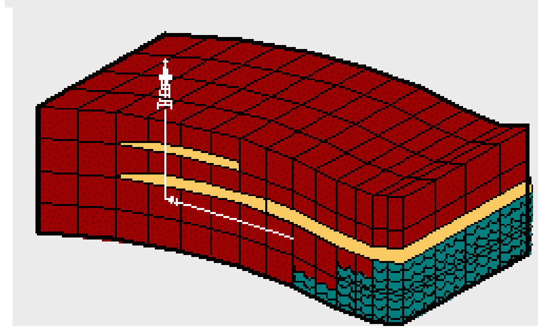
Step 3 – Select the Model

Determine the Approach



Detailed Geologic Description
May be matched to historic performance





Higher Uncertainty Properties

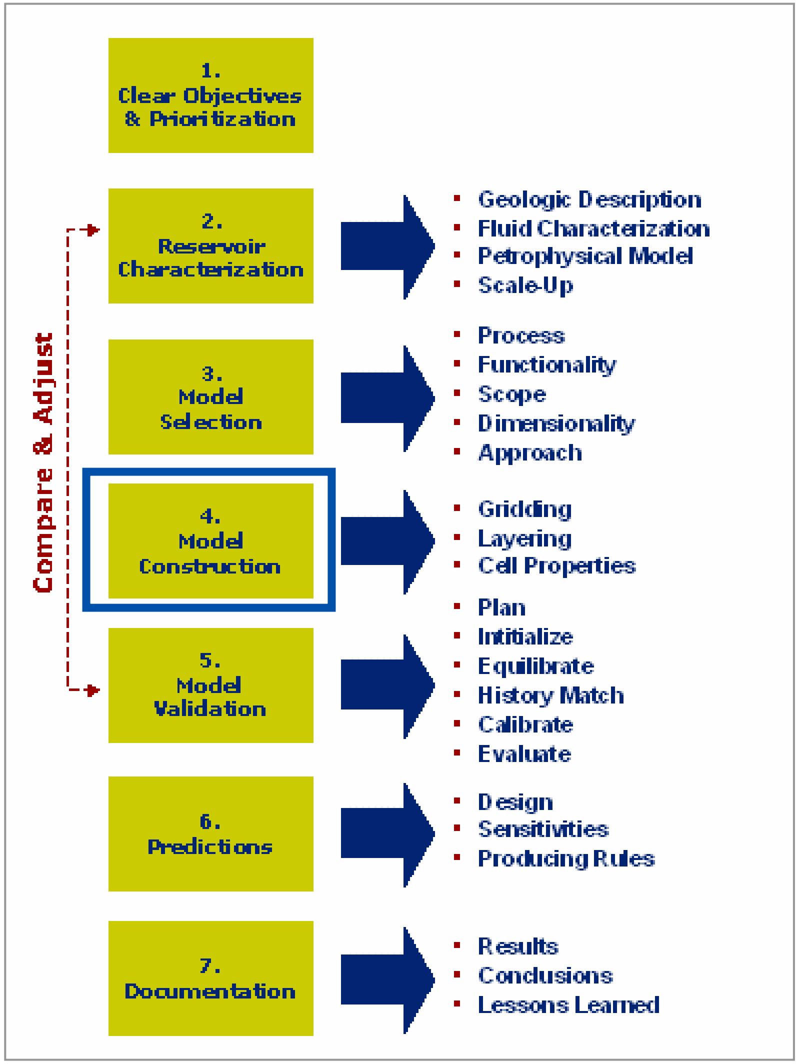
Step 3 – Select the Model

	Type	Advantages	Disadvantages	Suitability to Models	Unsuitability to Models
Functionality	Energy	Simplicity	Lacks accurate computation of phase saturation distribution	Material balance & pressure calculation in time are important	Saturation distributions in time are important (i.e., infill drilling, workover planning, individual well performance)
	Front-Tracking	Simplicity	Requires very fine gridding	Phase saturation tracking in reservoir is important	Large-scale field studies
	Energy / Front-Tracking	Allows accurate computation of reservoir pressures & phase saturations	More complex than energy & front tracking	Energy & phase saturation distributions in time are important	
Scope	Full-Field	Doesn't need scale-up to full field; separate boundary fluxes unneeded	More complex than slice mode	Scale-up of results from a slice to full-field is impractical	Simple parameter-sensitivity studies
	Slice	Simplicity	Must scale-up to full-field and separately estimate boundary fluxes	Scale-up of results from a slice to full-field can be done accurately.	1. Scale-up to full-field would be difficult (e.g., due to areal heterogeneities) 2. Cross-boundary fluxes are unknown and cannot be accurately estimated

Step 3 – Select the Model Dimensionality

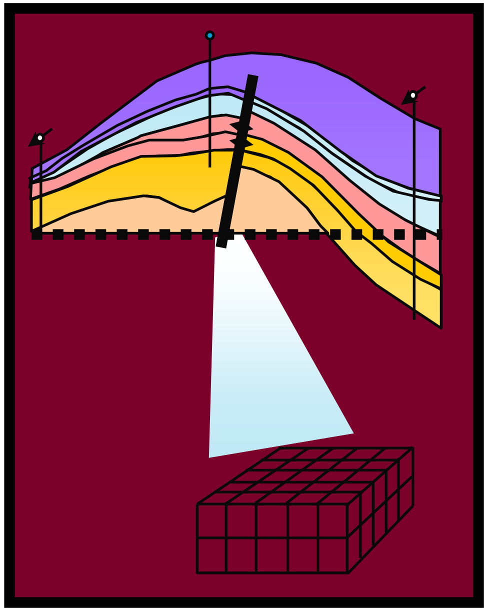
	Type	Advantages	Disadvantages	Suitability to Models	Unsuitability to Models
Dimensionality	0D/1D	Simplicity relative to 2D and 3D	Simulates dynamics in 0/1 dimensions	Dimensionality is not important	Solutions require analysis of 3D effects (e.g., study of near wellbore effects such as coning)
	2D	Simplicity relative to 3D	Simulates reservoir dynamics in only two dimensions	2D effects are being investigated	Solutions require analysis of 3D effects (e.g., study of near wellbore effects such as coning)
	3D	Simulates reservoir dynamics in 3D	More complex than 1D and 2D	3D effects are being investigated	Simple parameter-sensitivity studies
Approach	Actual	Allows actual characterization to validate model against field data	Complexity relative to conceptual	Allows actual characterization of reservoir	Reservoir and production data are sparse (i.e., virgin fields)
	Conceptual	Simplicity	No validation of model data	Reservoir data is lacking	Objectives necessitate validation (e.g., mature field development studies)

Key Steps in a Simulation Study

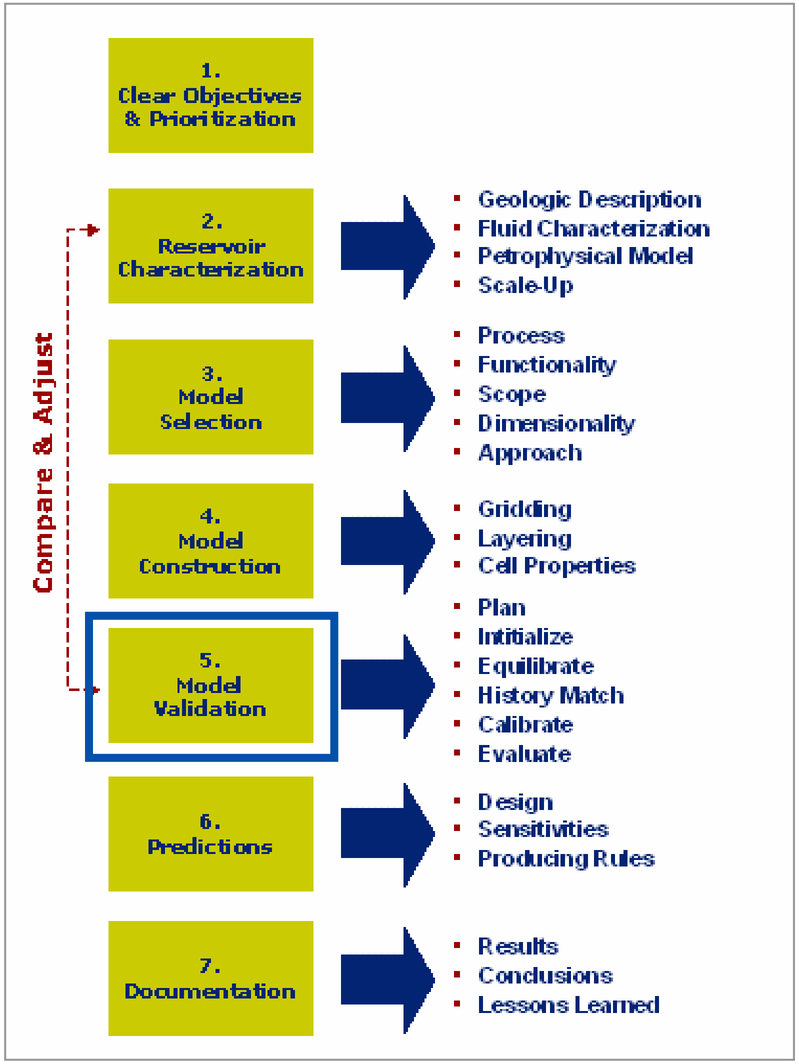


Step 4 – Construct the Model Converting the Earth Model into a Simulation Model

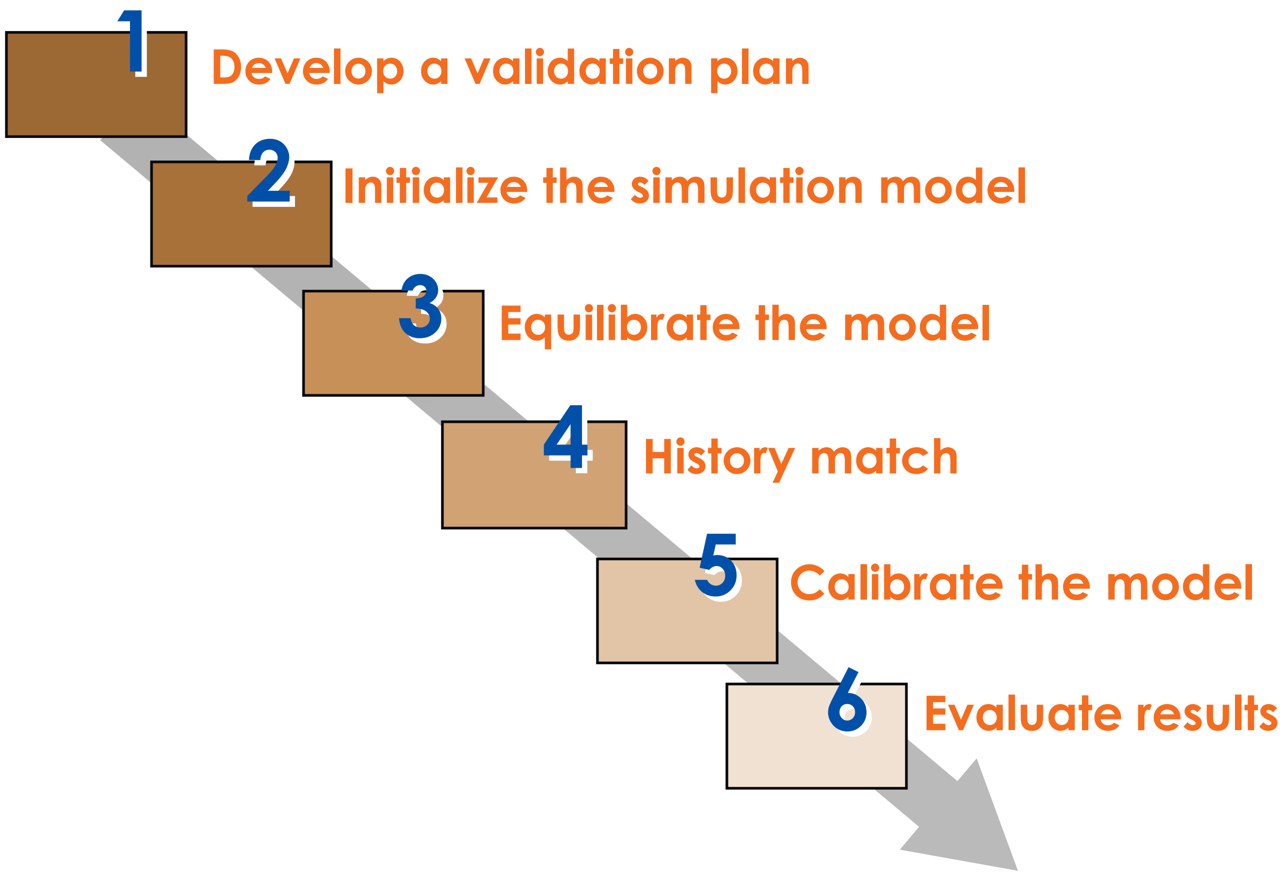
1. QC the geologic model for errors and problems
2. Scale-up the model
3. Output the model in simulation format
4. Output fault information for simulation
5. Intersect reservoir wells with the model and output simulation well data
6. Output production data in simulation formats and link to wells



Key Steps in a Simulation Study



Step 5 – Validate the Model

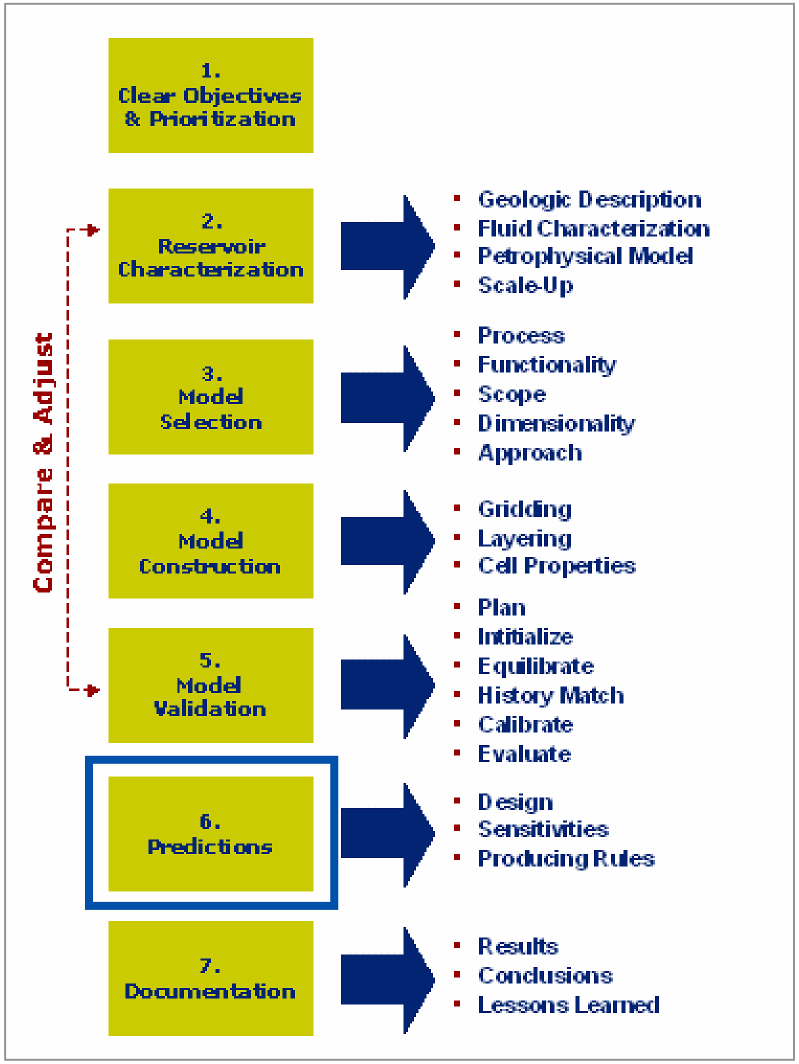


Step 5 – Validate the Model

Two *important* ideas for the proper validation of reservoir models:

- History Matching must not be achieved at the expense of parameter modifications that are physically and/or geologically wrong
- Even when a model is fully validated, simulation results will still have some degree of uncertainty

Key Steps in a Simulation Study

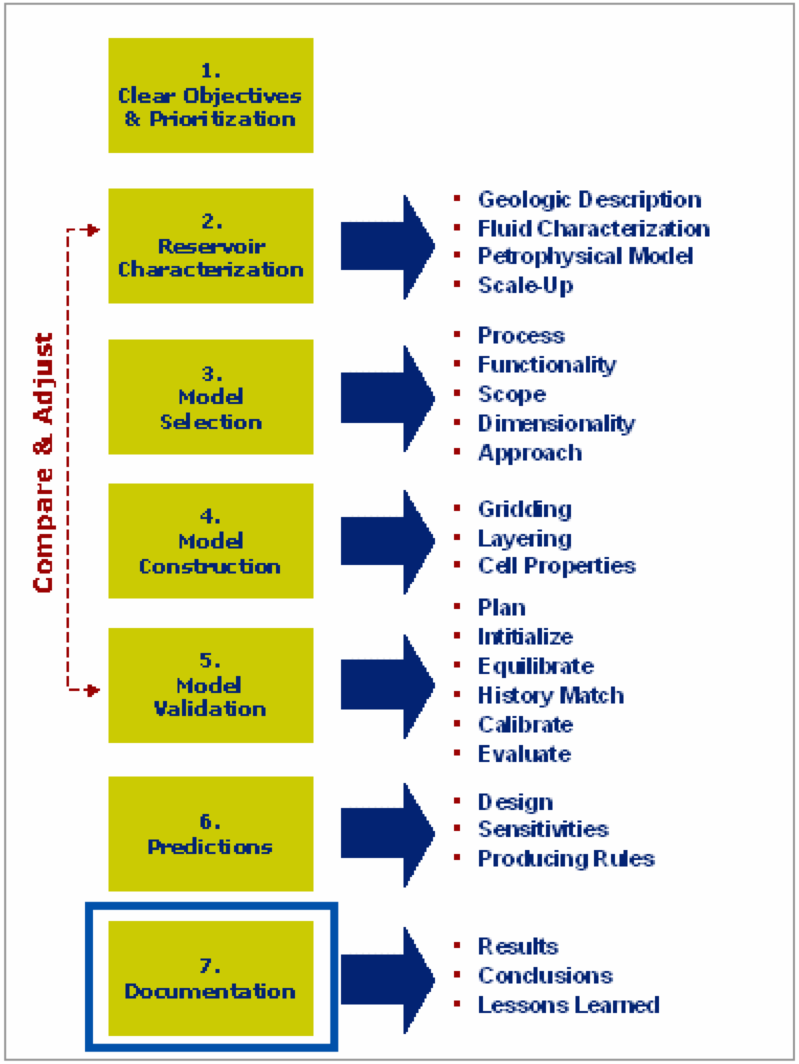


Step 6 – Make Predictions

Important considerations when making reservoir model predictions:

- Prediction cases shouldn’t exceed capabilities of the model.
- Predictions need to be consistent with field practices.
- Simulation yields a non-unique solution with inherent uncertainties from:
  - Lack of validation (e.g., reservoirs with sparse geologic or engineering data).
  - Modeling or mathematical constraints because of compromises made in model selection.
  - Inherent uncertainties in reservoir characterization and/or scale–up to model dimensions.

Key Steps in a Simulation Study

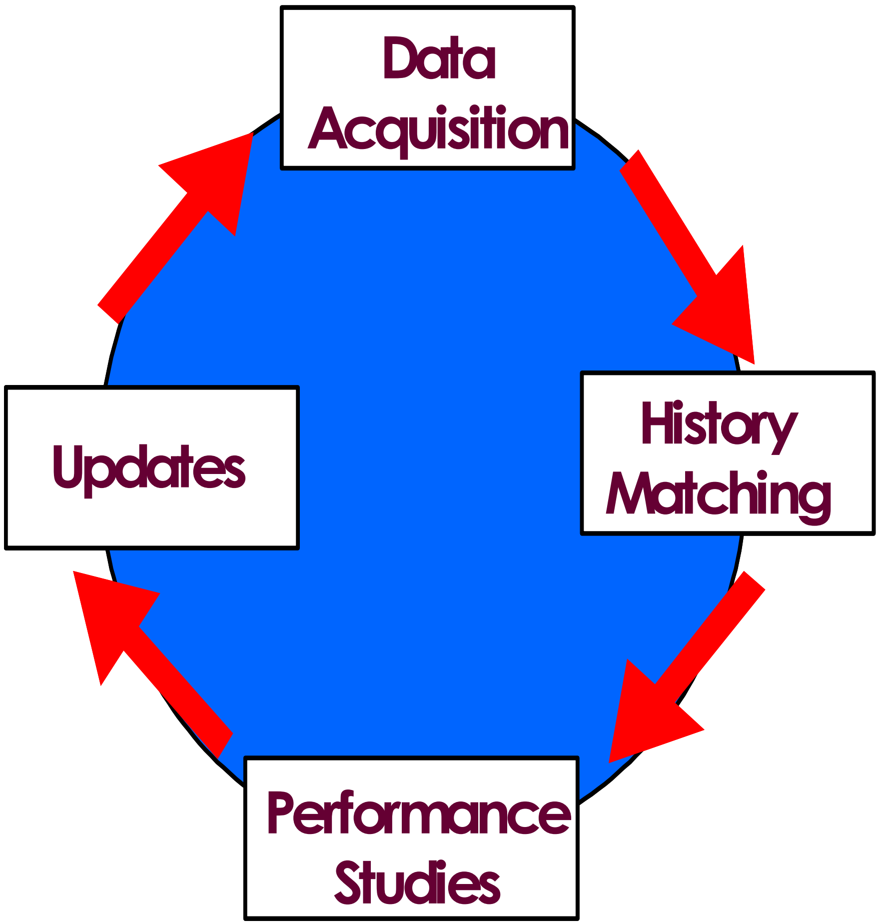


Step 7 – Document the Study

Methods to document studies

- Technical memorandum
- Formal report
- Presentation
- Store data files
- Share lessons learned with future project teams

Updating the Reservoir Simulation Study – Important for Large Field Studies



Reservoir Simulation Examples

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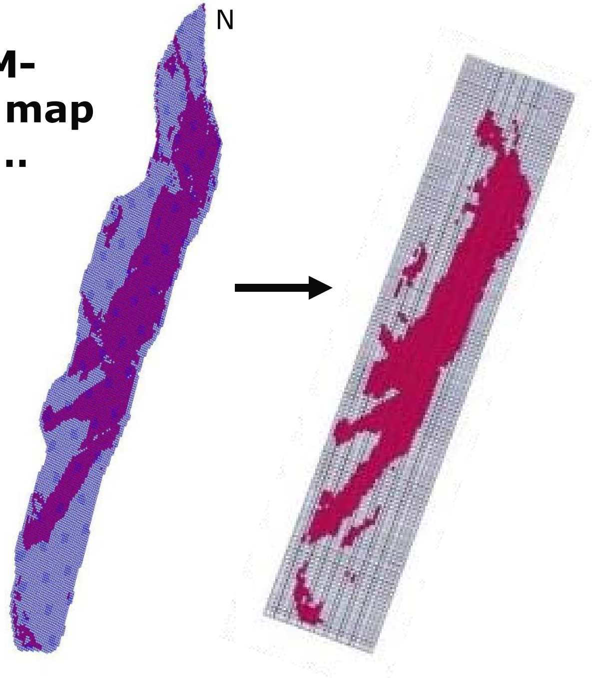
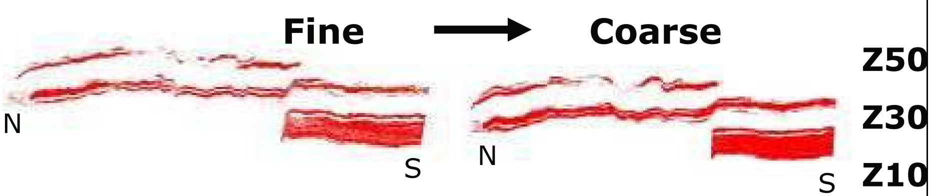
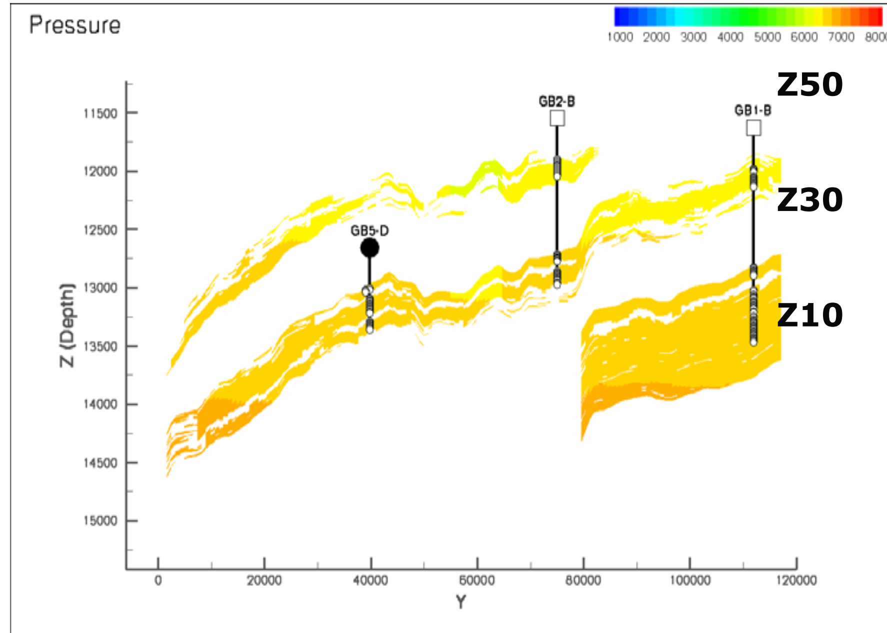
Dynamic Models (Main Zones Shown)

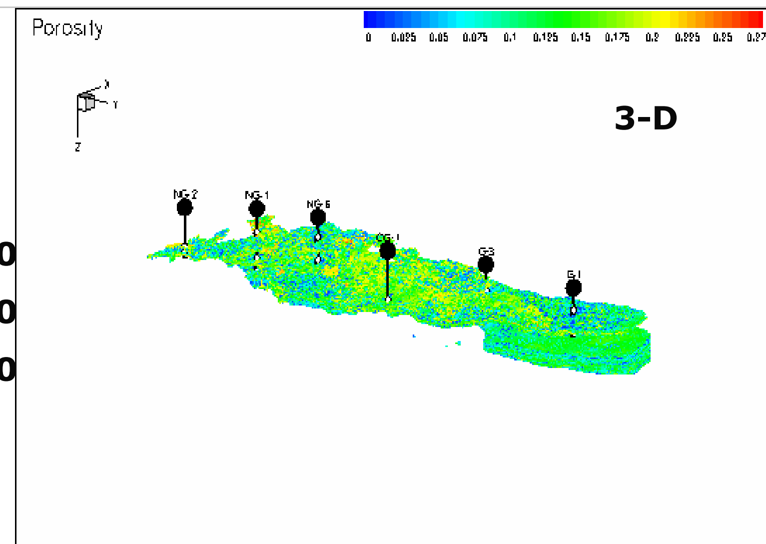
Main zones contain >85% of OGIP

Z30 M-sand map view…

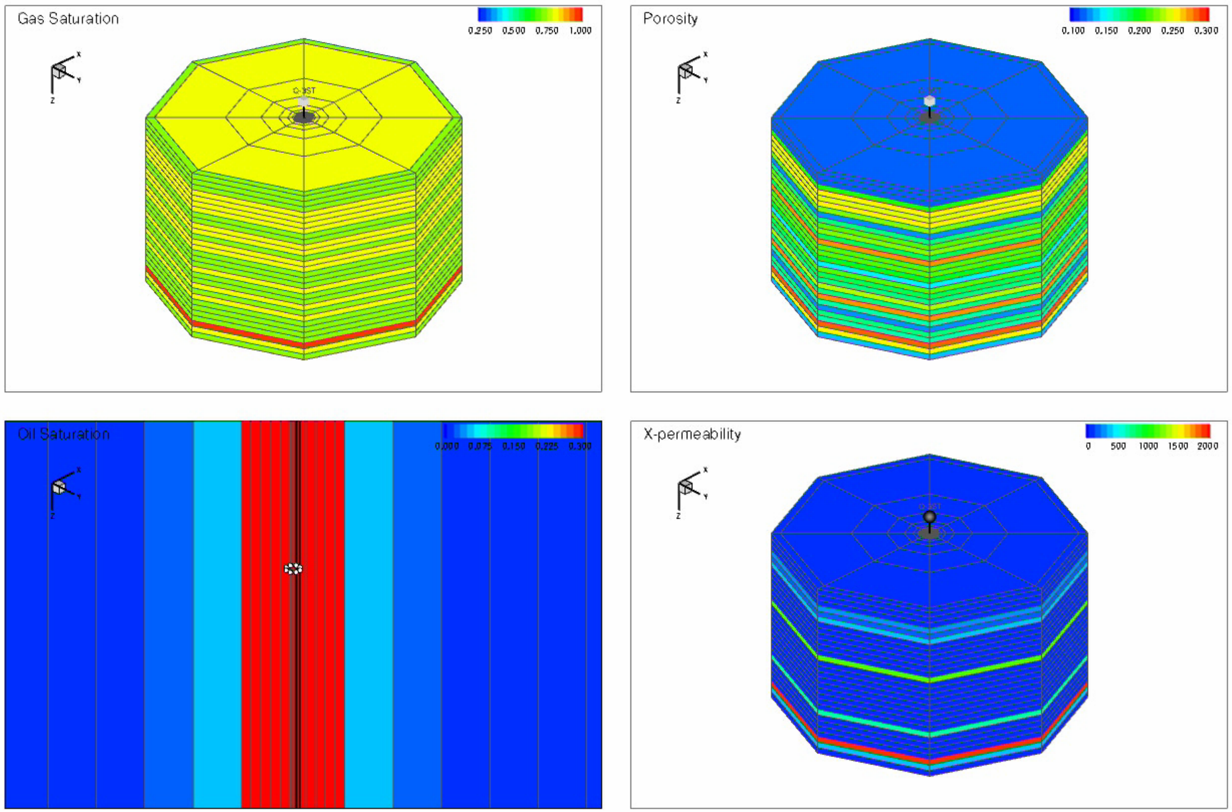






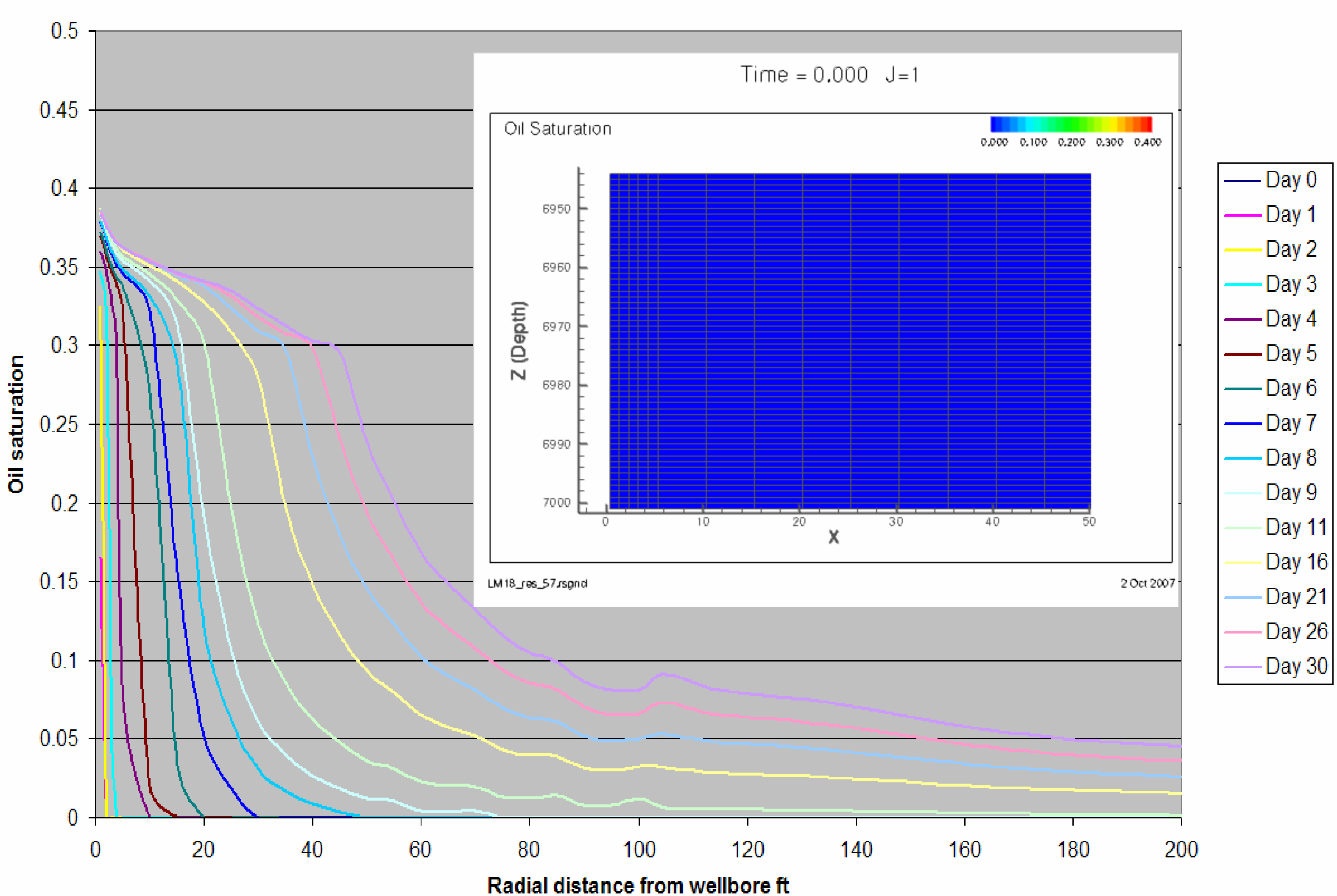


Condensate Banking – Single Well Model



- 1690 ft radius, 1ft blocks in K direction, 45 degree blocks in J direction.
- I = 33, J = 8, K varies between 29 and 57 MD.
- 3 relative permeability regions.
- Porosity from logs, perm from core correlation.

Lower Miocene Sand
DST match/Saturation Profile



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