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Introduction to Reservoir Simulation

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9th May 2018

SE-06 Production Optimisation Implementation Guide

- **2.1 Reservoir, wells and plant technical limits**

“*Understand the recovery technical limit and current predicted recovery, and then evaluate and select future recovery options (new wells, improved oil recovery, enhanced oil recovery, etc) to maximise economic recovery*”

Static and Dynamic Reservoir models are key elements for evaluating and selecting any future recovery options (infill wells, improved oil recovery, enhanced oil recovery)

2.2 Reservoir management plans

“*A model (static and dynamic) describing the distribution and characterisation of hydrocarbons in place and reserves*”

Static and Dynamic Reservoir models are key elements of a good reservoir management program.

Outline

- Reservoir engineering techniques for forecast, reserves estimation and reservoir behaviour prediction
    - Analogues
    - Decline curves analysis
    - Material Balance
    - Reservoir simulation
- Reservoir simulation background
- Model purposes
- Model contents vs. complexity
- Reservoir model elements

Outline

- Probability and Determinism (reservoir model components)
- Static model
- Grid
- Rock property modelling
- Dynamic model
- Major laws used in reservoir simulation
- Numerical techniques in reservoir simulation
- Scale/Upscale
- Pseudo/ Effective property
- Black oil model/Compositional model

Outline

- Reservoir simulation task
- History match
- Uncertainty handling
- Field applications

Modelling techniques through the field life

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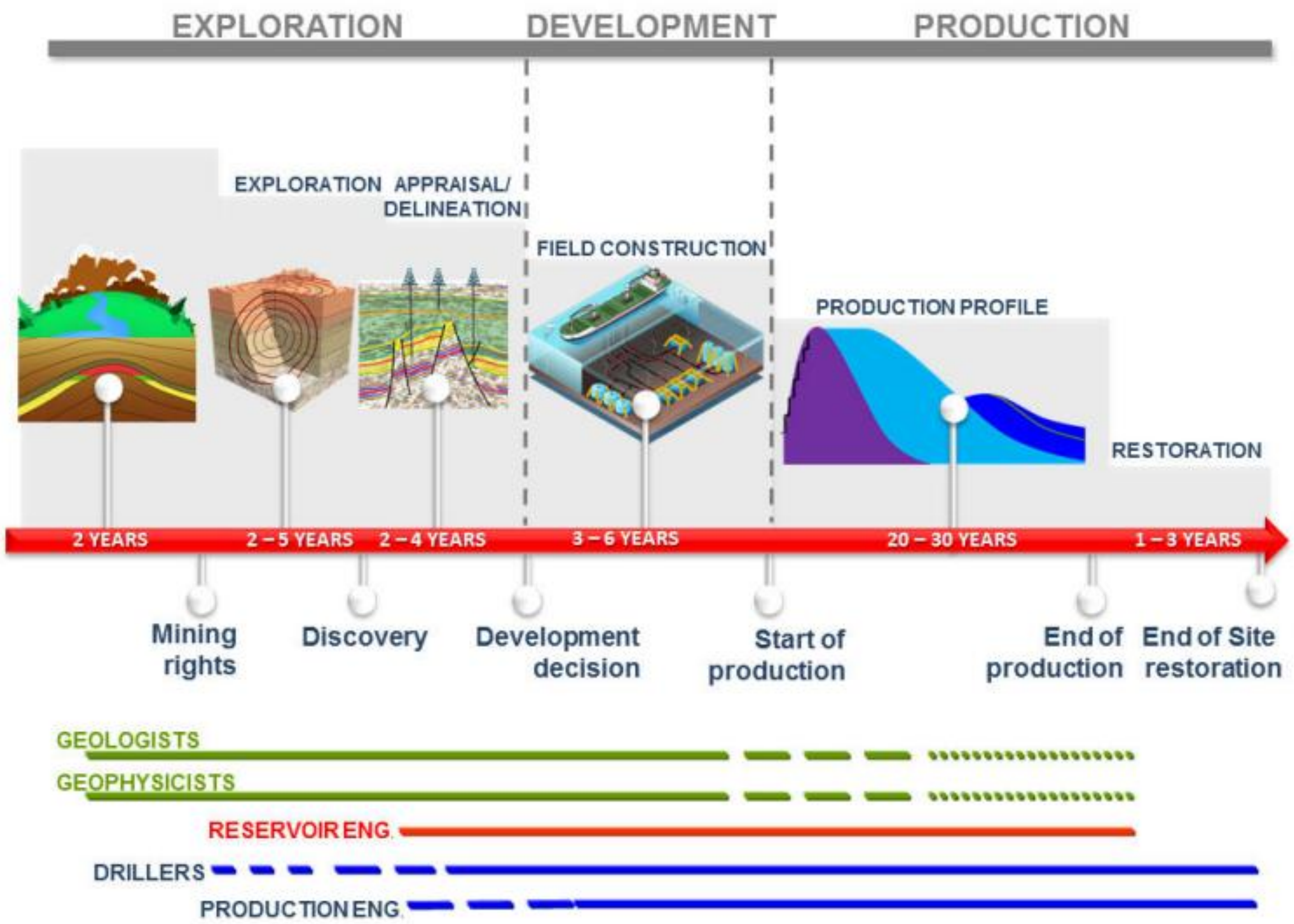
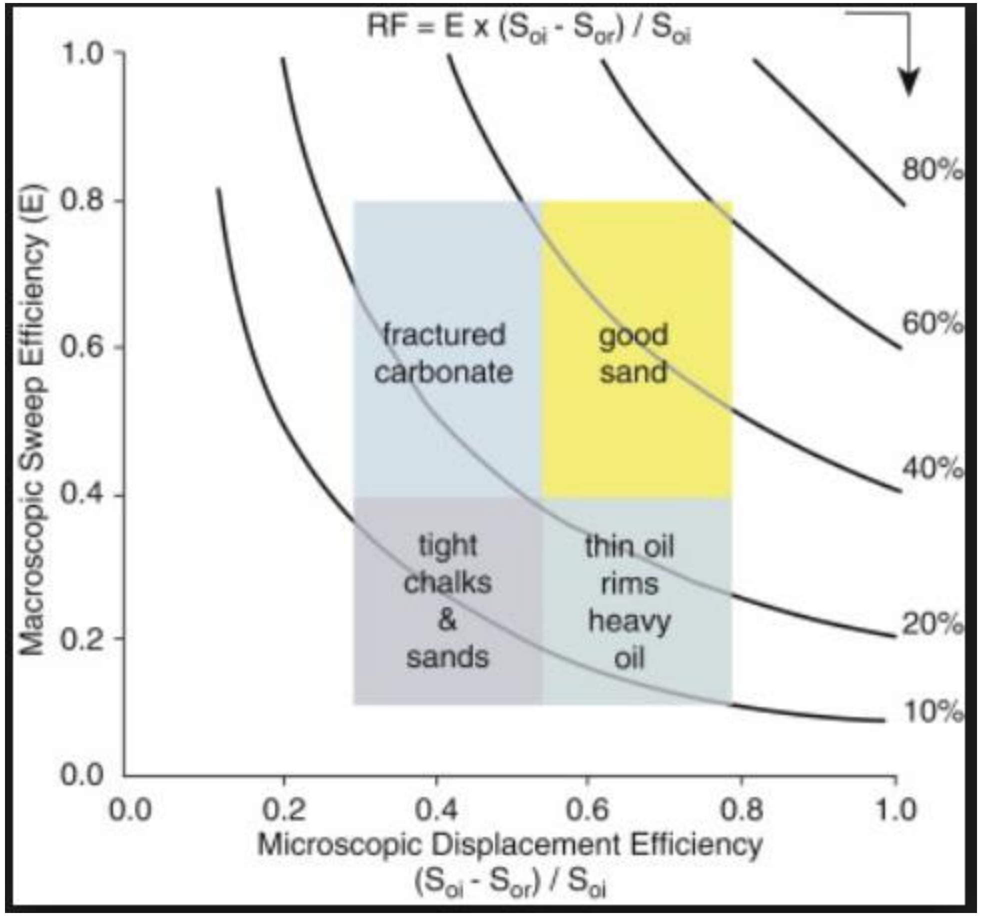
- Analogues
- Decline curves analysis
- Material Balance
- Reservoir simulation

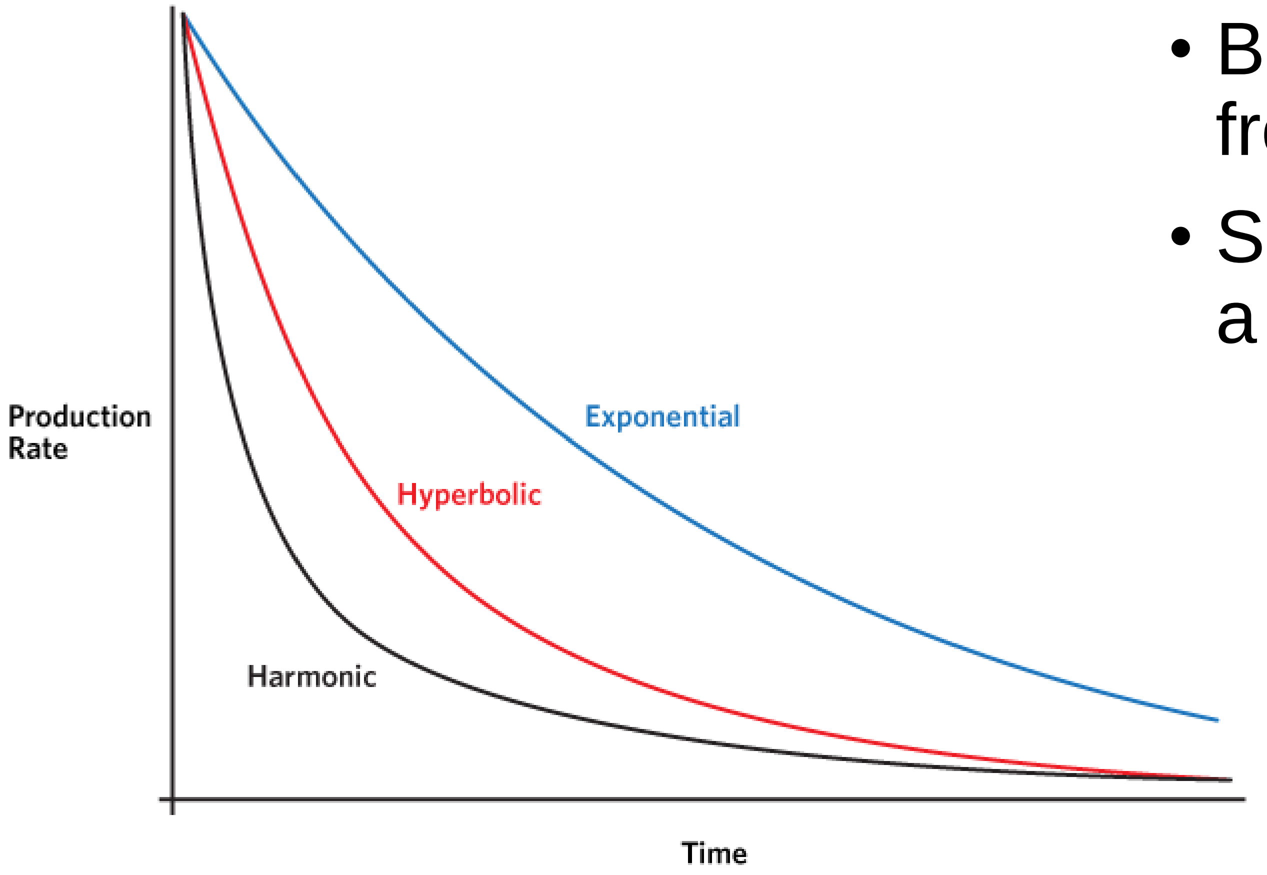


Use of Analogues for RF estimation

- Analogues uses for benchmarking of mature fields
- For RF estimation for prospect evaluation



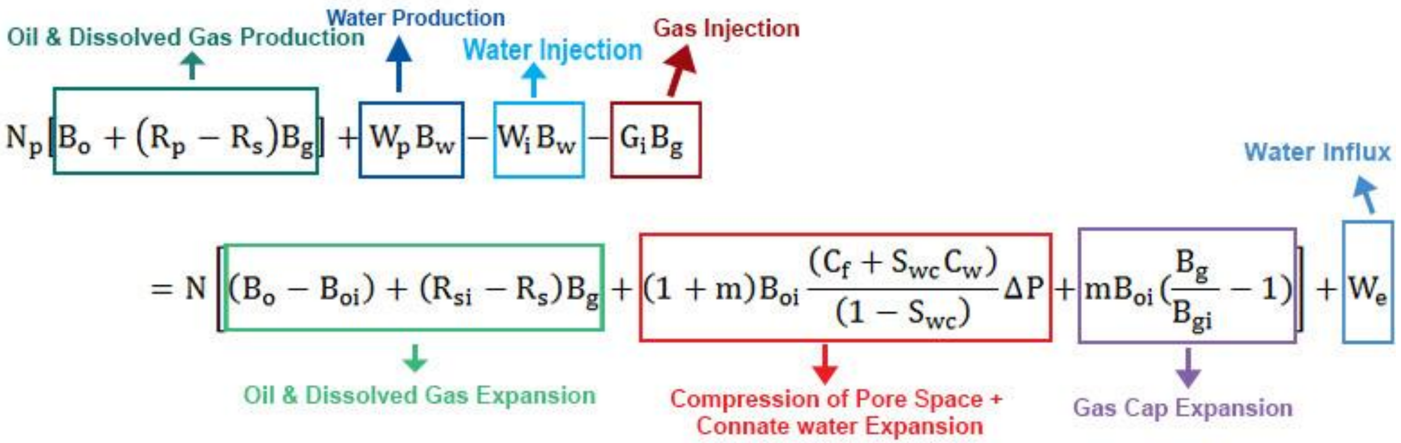
Decline curves analysis



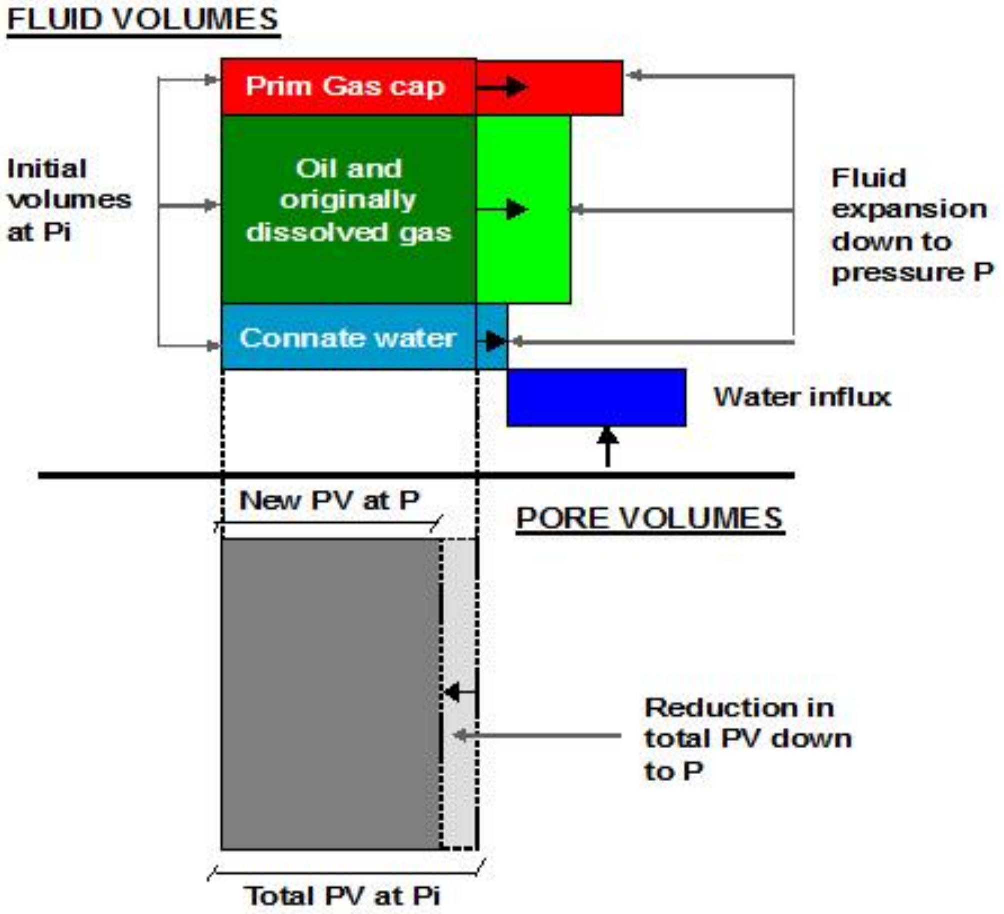
- Basic tool forecasting production from a well or well group
- Sufficient production to establish a decline trend

Material Balance

- An alternative, largely independent method of estimating the original hydrocarbons in-place (OOIP and OGIP)
- Sufficient production data



$$N_p\left[B_o + (R_p - R_s)B_g\right] + W_p B_w - W_i B_w - G_i B_g = N\left[(B_o - B_{oi}) + (R_{si} - R_s)B_g + (1+m)B_{oi}\frac{(C_f + S_{wc}C_w)}{(1 - S_{wc})}\Delta P + mB_{oi}\left(\frac{B_g}{B_{gi}} - 1\right)\right] + W_e$$



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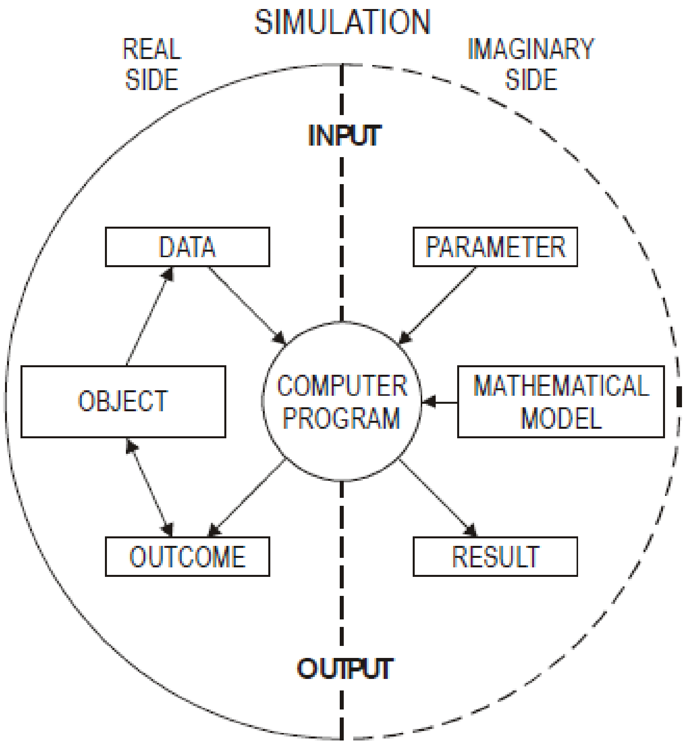
Reservoir Simulation

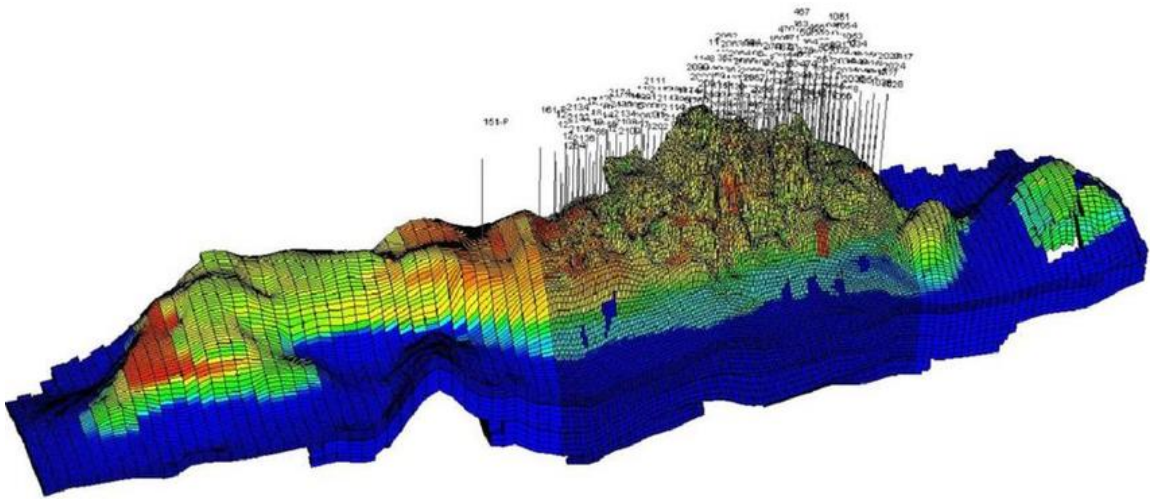
Reservoir simulation

- A tool developed by combing physics, mathematics, reservoir engineering, and computer programming for predicting hydrocarbon reservoir performance under various operating strategies
- Gain insight into the recovery processes of a reservoir



Advanced Petroleum Reservoir Simulation, M.R. Islam

Reservoir Simulation



- Reservoir simulation leading to prediction of reservoir behaviour
- Reservoir simulation studies are very subjective and vary from simulator to simulator.
- Currently available simulators only address a very limited range of solutions for a particular reservoir engineering problem.

“Garbage in Garbage out (GIGO)”

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A computer program based on the mathematical model needs input!

Required reliable data?

No simulator can replace reliable data or the brain of the user.

History of reservoir simulation

- **1950 – 1970,** Two/Three dimensions, simple geometry, black oil fluid, well conning, multiple wells
- **1970 – 1980,** Compositional, thermal, miscible
- **1980 – 1990,** Complex well management, fractured reservoirs, special gridding at faults, graphic interface
- **1990s** –Advanced GUIs, integration with geo-modelling, geomechanics, parallel computer techniques, local grid refinement

Reservoir model purposes

- Estimate field performance
- Development Planning
- Visualisation
- Volumetric calculation
- Well planning
- Probabilistic models
- Input to seismic modelling

Model contents vs. complexity

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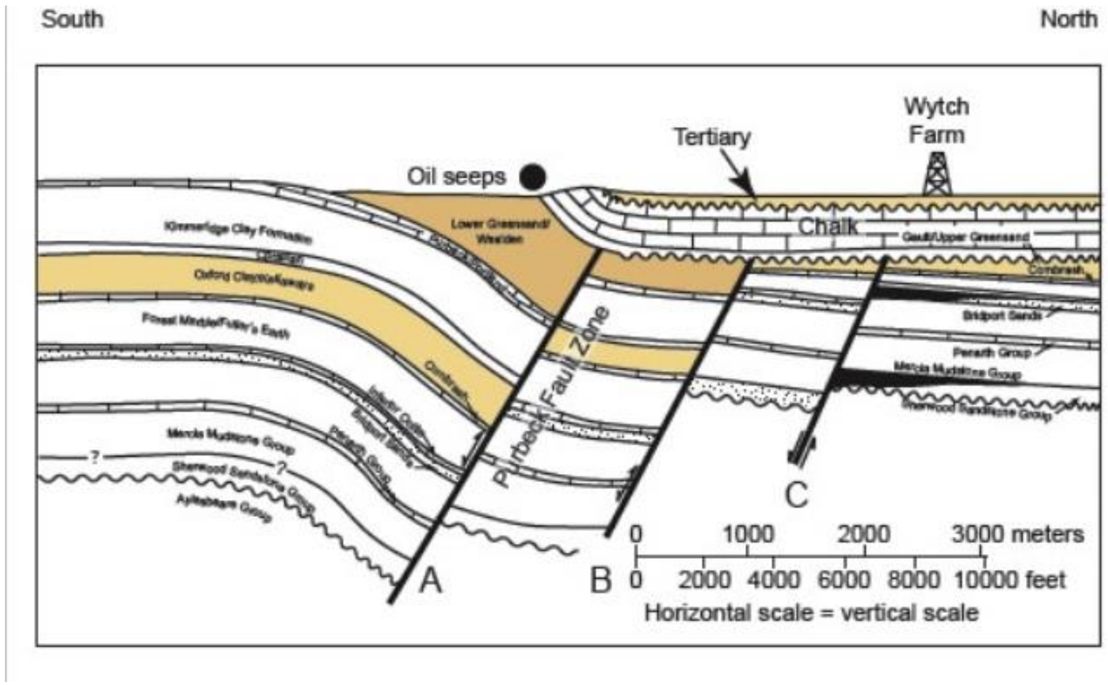
- *“In reservoir simulation, the question is not whether, but how and how much. The complexity of the questions being asked, and the amount and reliability of the data available, must determine the sophistication of the system to be used.”*



Based on Underhill 1998

Model contents vs. complexity

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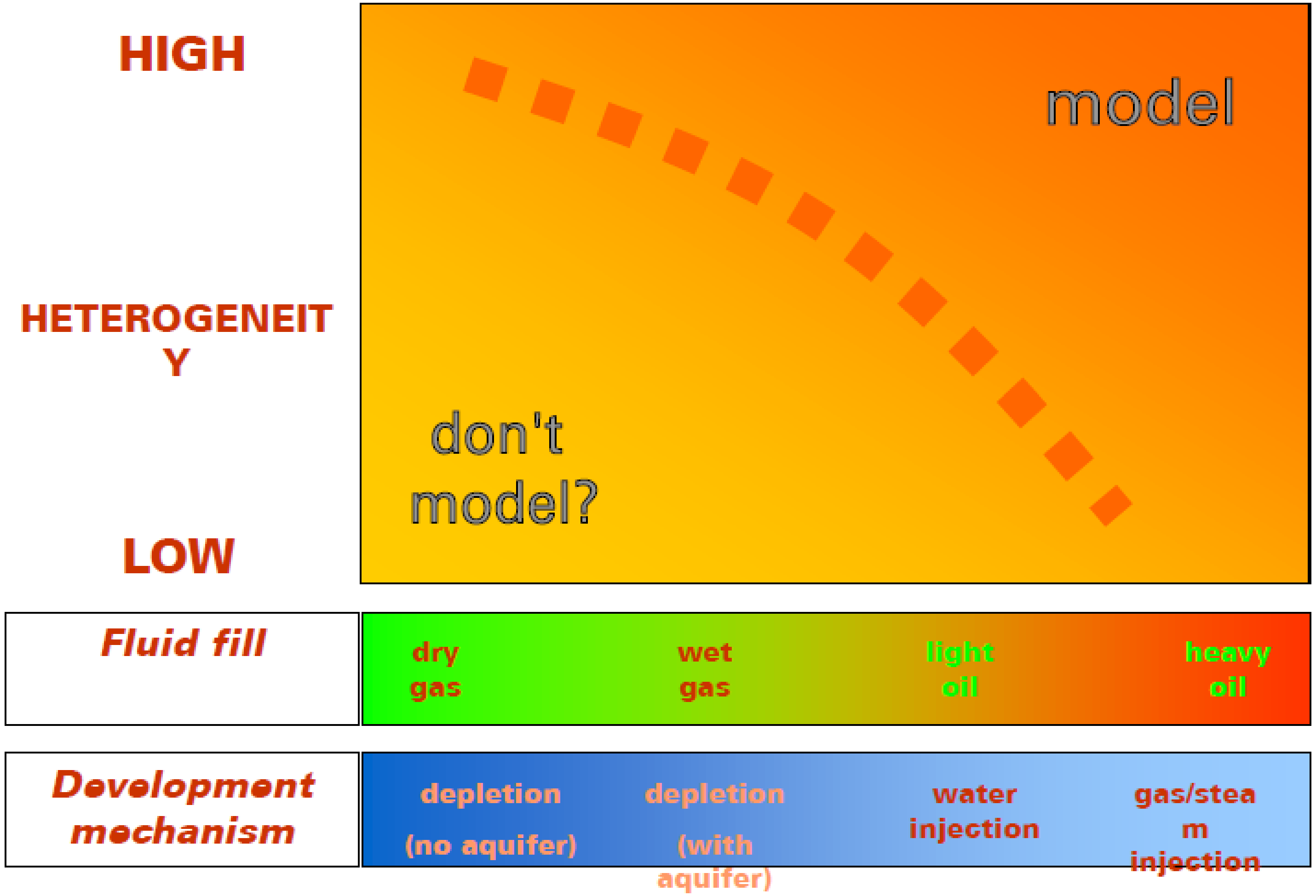
- Build a model?



Reservoir Model Design, Mark Bentley

Reservoir simulation elements

- Geological description
  - Probabilistic or deterministic
- Fluid Type
  - Black oil / Compositional
- Reservoir depletion mechanism

Probabilistic and Deterministic

Deterministic

- All necessary data is known before
- Can tell exactly what is going to happen, once the system starts.
- *Example.* Conversion between ft and meter is deterministic
- The process of calculating the output is deterministic process

Probabilistic

- Element of chance is involved
- Don’t see exactly when it will occur, but the possibility is known
- *Example.* Roll a die until it comes up ‘3’.
- Know that in each roll, a ‘3’ will come up with probability 1/6.

Reservoir models
(Probabilistic and Deterministic components)

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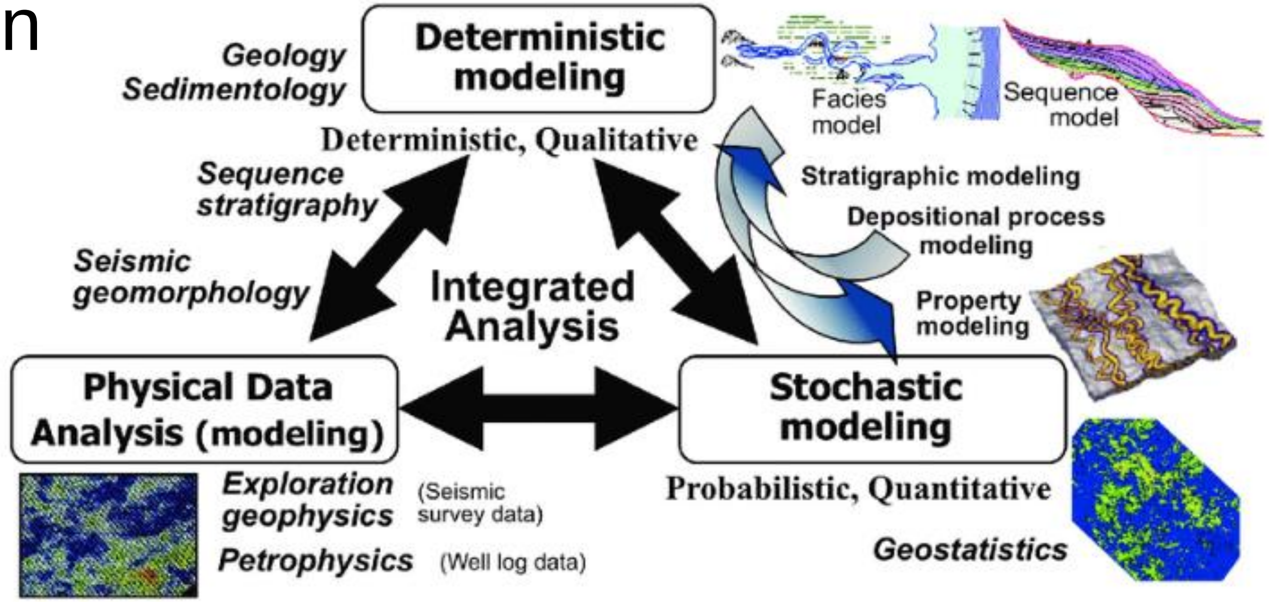
- All reservoir models elements are a combination of probabilistic and deterministic components



3D geology and reservoir modelling in oil industry: Geologic model construction by integration of sedimentology, sequence stratigraphy seismic geomorphology, exploration geophysics and geostatistics, Osamu Takano, Journal of the Geological of Japan, Jan 2013

Static model

- Geocellular modelling
  - The process of generating a model of the subsurface
  - The physical properties of the reservoir are stored at the grid point
- Steps
  - Define a proper GRID
  - Structure modelling
  - Stratigraphic modelling
  - Lithological modelling
  - Petrophysical modelling

Grid

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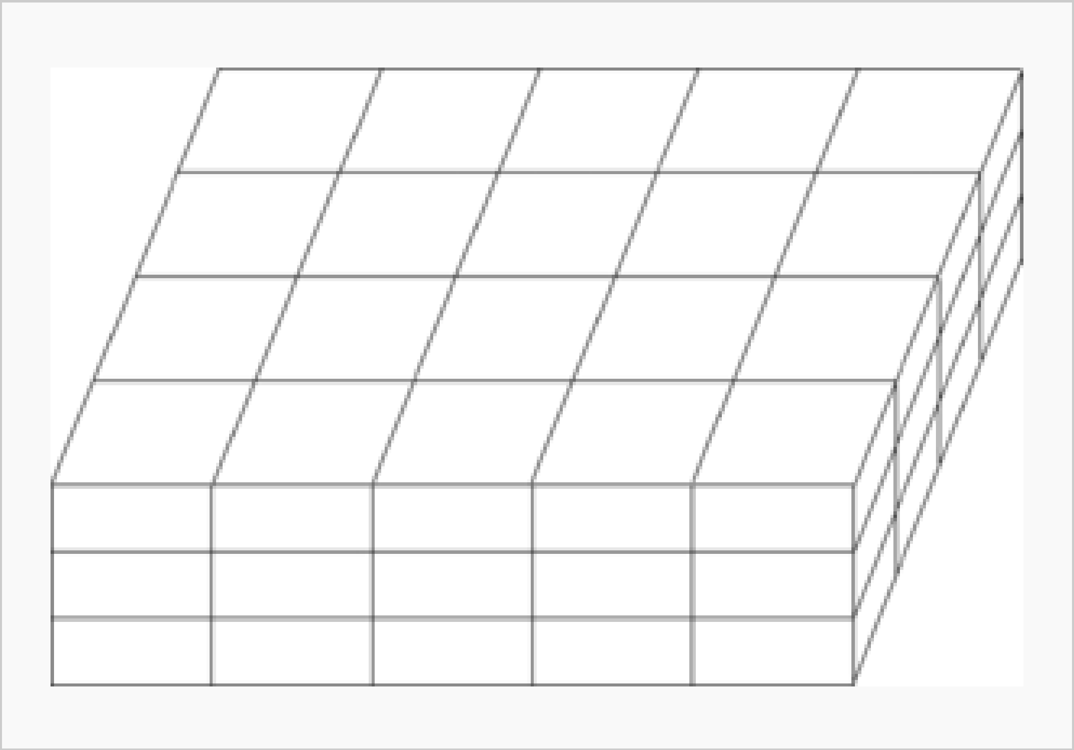
- The aim of gridding in reservoir simulation is to turn the geological model of the field into a discrete system which the fluid flow equation can be solved.
  - Common grid co-ordinate syster
    - Cartesian
    - Cylindrical



Grid

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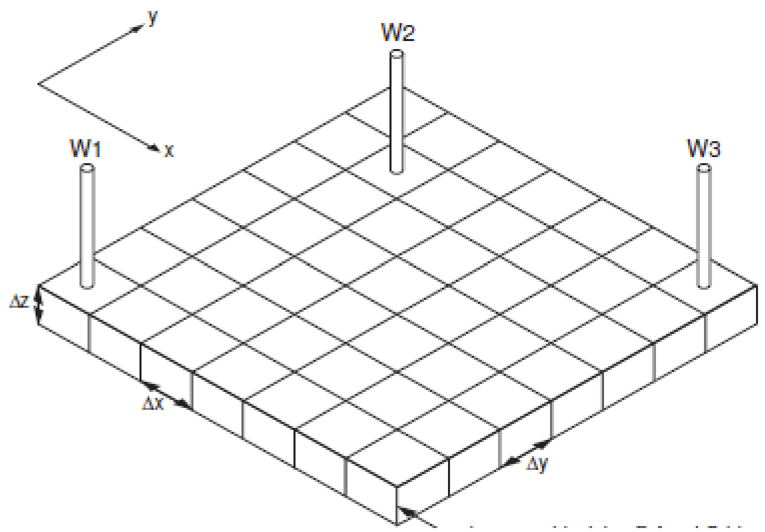
- How we divide or discretize, geological model into divisions of ΔX, ΔY, ΔZ. We always “Shup-up” the reservoir into block and then we model the block to block and then we model the block to block.
- Temporal Discretisation
  - This is the process of dividing up the time step into divisions of Δt



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Grid

- Oil and gas reservoirs structure is a set of geological horizons representing bedding planes
- Two related issues are involved in choosing a grid for reservoir simulation:
  - Accuracy with which the geological description of the reservoir is matched
  - Discretisation of the flow equations

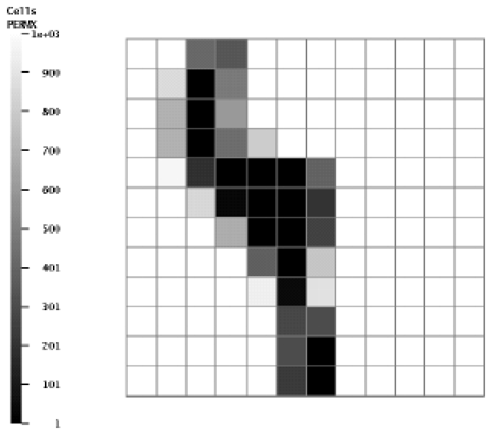

Figure 4: Coarse regular grid

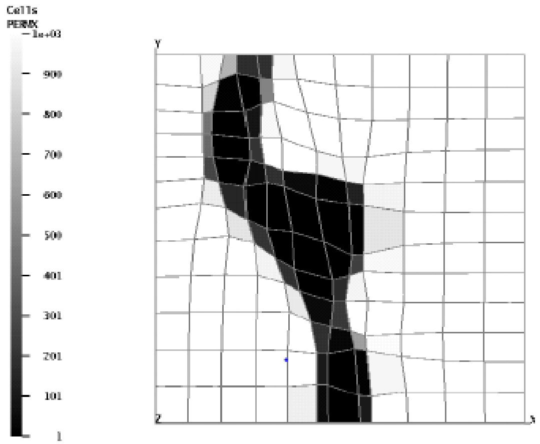

Figure 5: Geology-adapted grid

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Rock Property modelling

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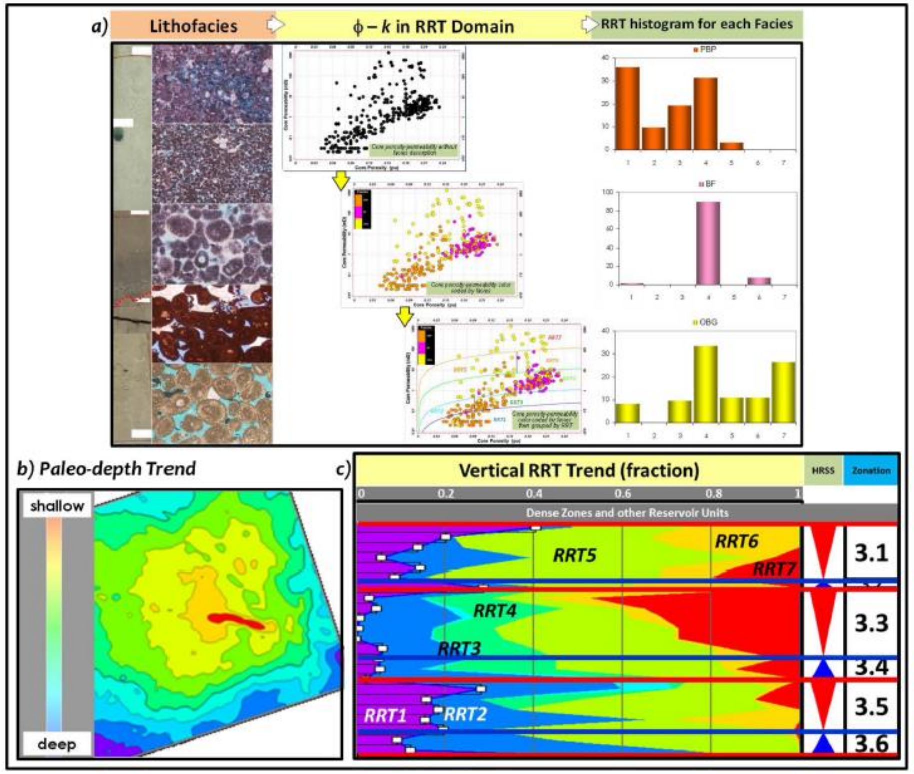
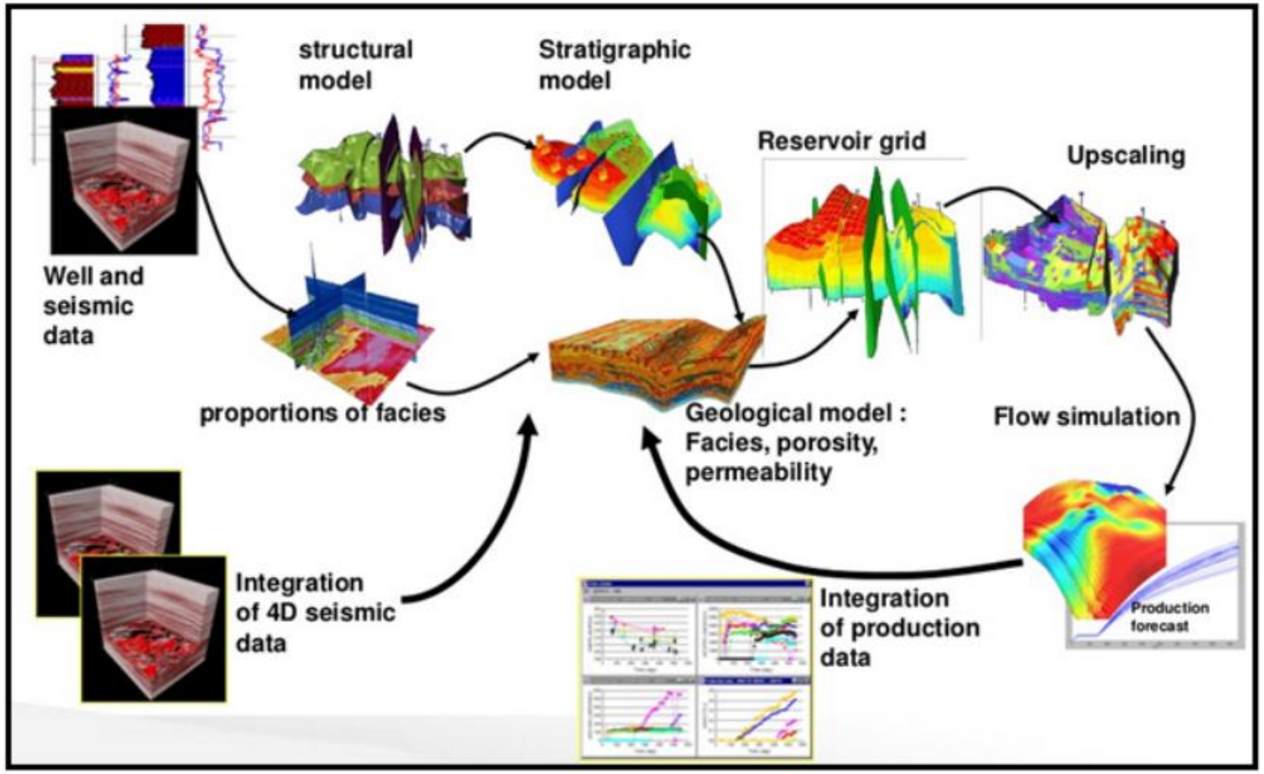
- Given difficulty of measuring rock properties, it is common to use geostatical methods to make realisation of permeability, porosity and water saturation.



Dynamic model

- Once the static modelling has been completed, the next step is building dynamic model and validate it using the production data and well test.
- This model is used for forecasting and field development planning

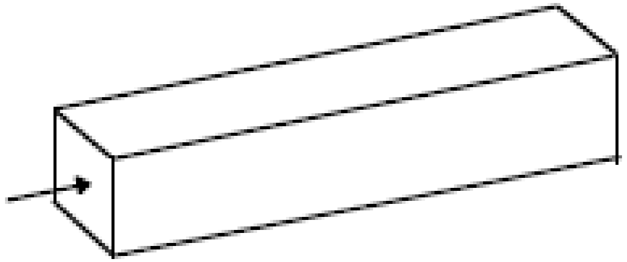


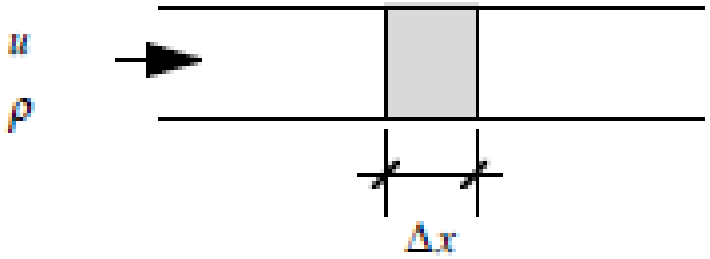
Major laws used in reservoir simulation

- Conservation of mass
- Conservation of momentum
- Conservation of energy

Mass Conservation

- Flow equations for flow in porous materials are based on a set of mass, momentum and energy conservation equations, and constitutive equations for the fluids and the porous material involved.





$$\begin{Bmatrix}\text{Mass into the} \\ \text{element at } x\end{Bmatrix} - \begin{Bmatrix}\text{Mass out of the} \\ \text{element at } x+\Delta x\end{Bmatrix} = \begin{Bmatrix}\text{Rate of change of mass} \\ \text{inside the element}\end{Bmatrix},$$

or

$$\{u\rho A\}_x - \{u\rho A\}_{x+\Delta x} = \frac{\partial}{\partial t}\{\phi A \Delta x \rho\}.$$

Conservation of momentum

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- Conservation of momentum is governed by the Navier-Stokes equations, but is normally simplified for low velocity flow in porous materials to be described by the semi-empirical Darcy's equation, which for single phase, one dimensional, horizontal flow is:

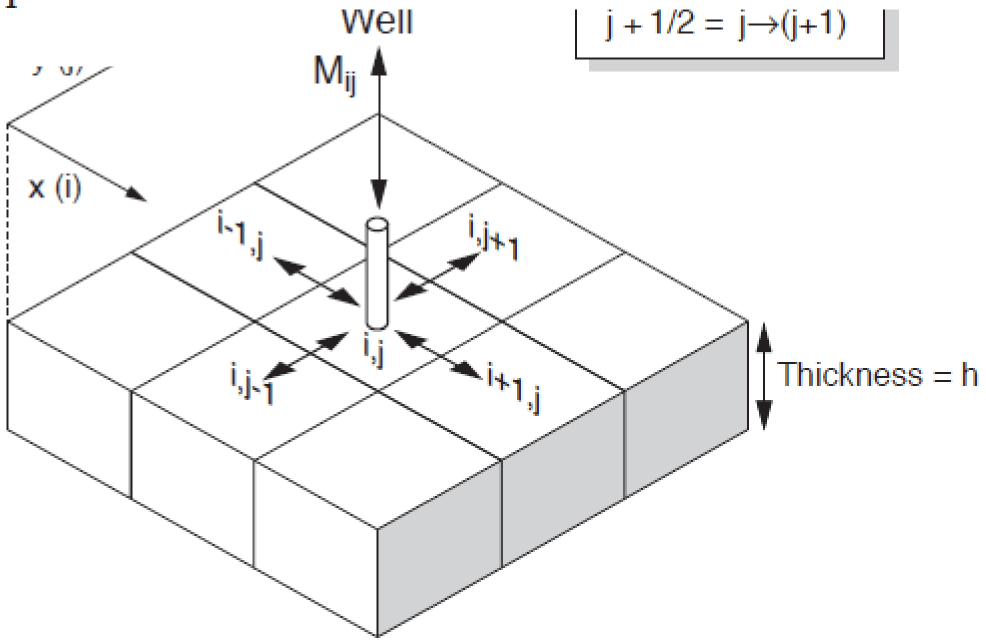
$$u = -\frac{k}{\mu}\frac{\partial P}{\partial x}.$$

Flow Equations in Reservoir Models

SATURATION $$\frac{\partial}{\partial t}\left(\frac{\phi S_o}{B_o}\right) = \frac{\partial}{\partial x}\left[\frac{k\,k_{ro}}{\mu_o B_o}\left[\left(\frac{\partial P_o}{\partial x}\right) - \rho_o g \frac{\partial z}{\partial x}\right]\right]$$

PRESSURE $$\phi\alpha(S_o;P_o)\left(\frac{\partial P}{\partial t}\right) = B_o \cdot \frac{\partial}{\partial x}\left[\frac{k\,k_{ro}}{\mu_o B_o}\left(\frac{\partial P_o}{\partial x}\right)\right] + \text{gravity terms} + \text{cap. terms}$$

etc.



Mathematical solution

- Exact analytical solution not exist
- Mathematical techniques used
  - Homogenization, volumetric average
  - Numerical methods e.g. finite difference, finite volume, finite elements methods

Numerical Methods in Reservoir Simulation

- Pressure equation would be a set of linear equations if the coefficients were known at the current time step (n). Hence, can be solve as "*linear system of equations*" by time-lagging the coefficients. Which will give a "*first guess*" to find the "*unknowns*".

- The same problem exist for saturation equation. If we have the "first guess" for $P_i n$+1 then we could use the latest value of pressure, time-lag the coefficient and use the saturation expression as it was an explicit expression.

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- This would give us and updated value of S_o $^{n+1}$ which then can be used back in the pressure equation and the whole process could be iterated until convergence. IMPES strategy for solving the two phase pressure and saturation equations
- By taken time-lagged values for the saturations, the pressure equation is linearized and can then be solved *implicitly* for the pressure for that iteration. The saturation can then be obtained *explicitly*; using the latest pressures and the most recent iteration for the saturation.

IMPES: IMplicit in Pressure Explicit in Saturation

Scale/Upscale

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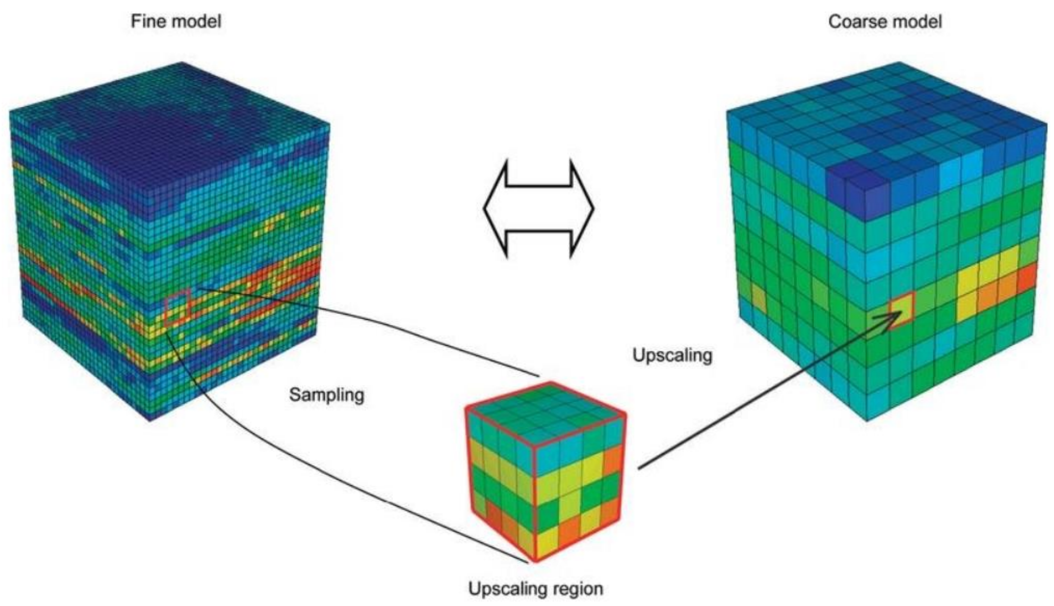
- Upscaling, or homogenisation, is substituting a heterogeneous property region consisting of fine grid cells with an equivalent homogeneous region made up of a single coarse-grid cell with an effective property value
- Upscaling is performed for each of the cells in the coarse grid and for each of the grid properties needed in the reservoir flow-simulation model.
- Fast enough for timely decision

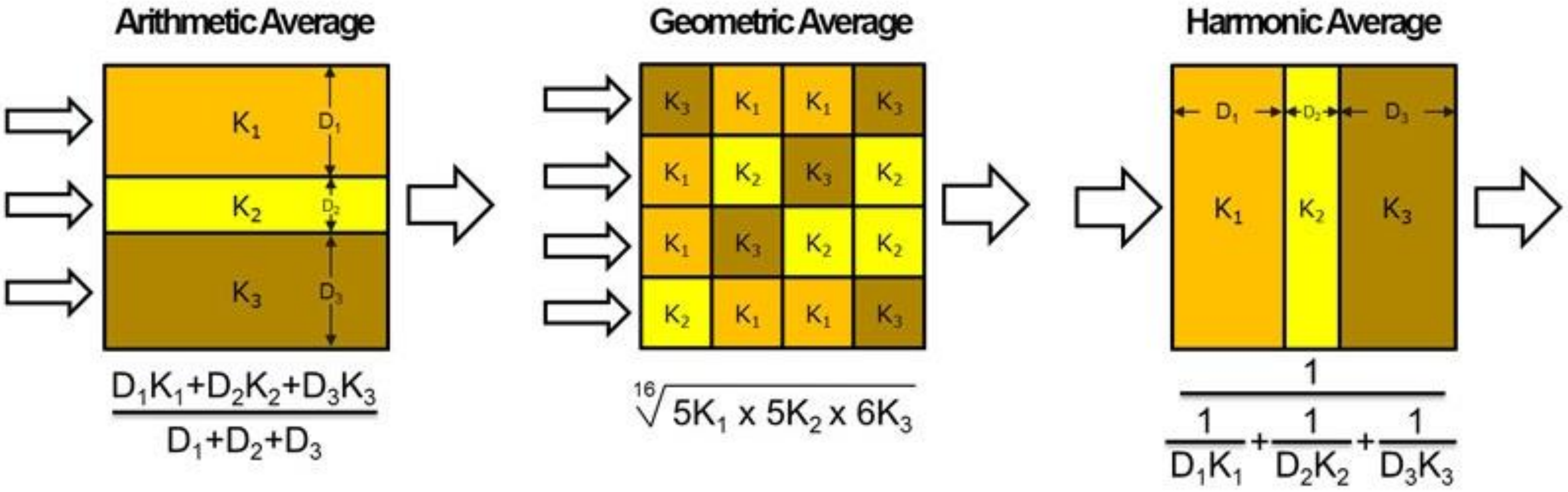


Pseudo property

- Refers to the value of a property or function (e.g. permeability or relative permeability) which is an average or effective value at a certain scale – usually the grid block scale.
- For example, we might put a value k=150 md in a simulator grid block which is 200 ft x 200 ft x 30 ft. This incorporate a large amount of geological substructure and permeability may vary significantly in different parts of this block.
- Additionally, there are different approaches to calculate the average value for an specific property, i.e. permeability.

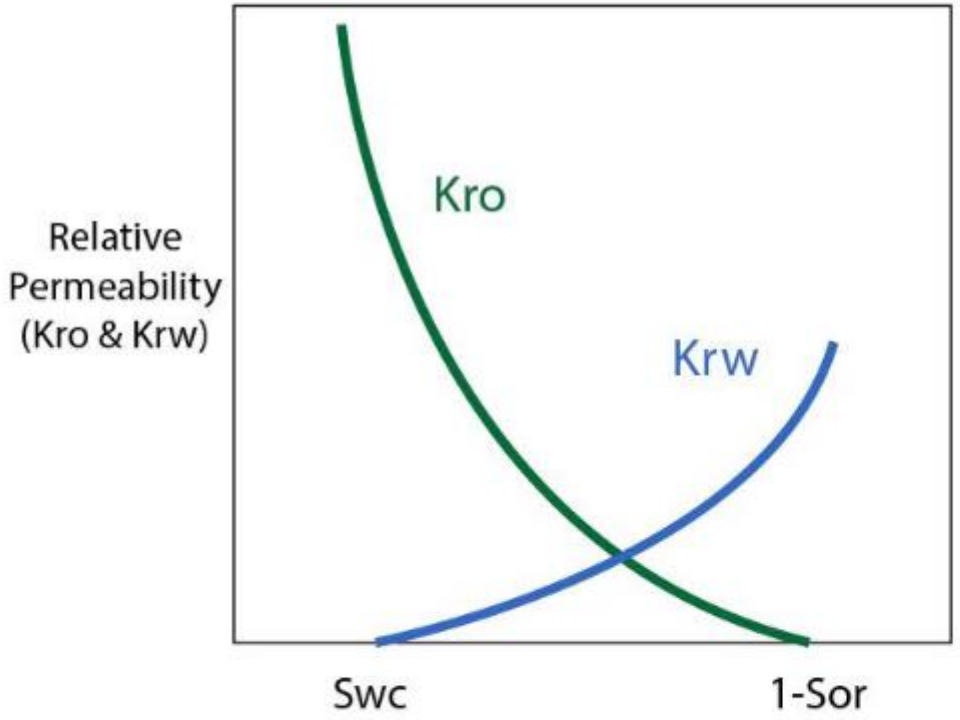
Pseudo property Averaging

- Measured on core plugs



Effective properties

- In multiphase flow in porous media, the relative **permeability** of a phase is a dimensionless measure of the **effective permeability** of that phase.
- It is the ratio of the **effective permeability** of that phase to the absolute **permeability**.
- It can be viewed as an adaptation of Darcy's law to multiphase flow.



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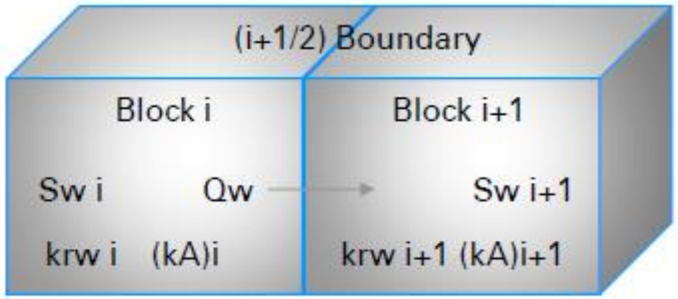
Transmissibility

- The transmissibility between two blocks is the measure of how easily fluids flow between them. The mathematical expression for two phase flow between grid block i and (i+1), for water:



$$Q_w = (kA)_{i+1/2}\left(\frac{k_{rw}}{\mu_w \beta_w}\right)_{i+1/2}\frac{(P_{i+1} - P_i)}{\Delta x}$$

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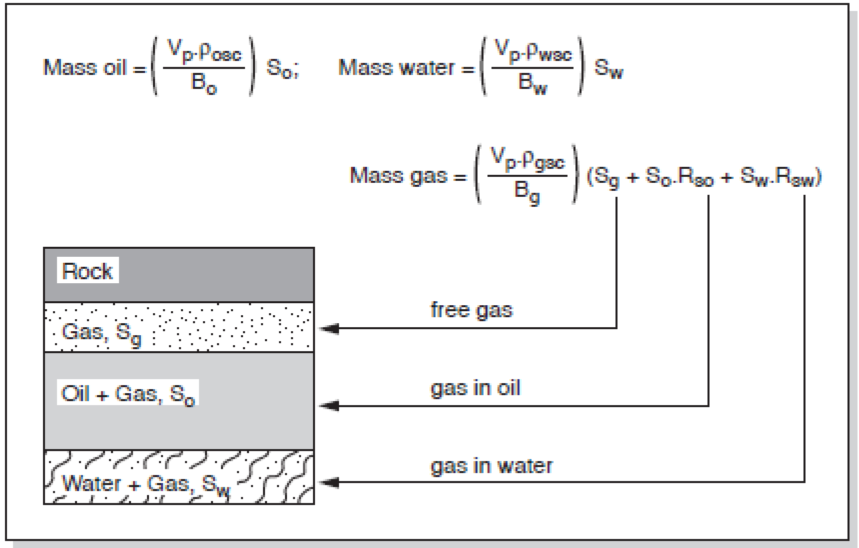
Black oil model

- The phases are treated as components
- Common approach to model immiscible two or three phases flow processes in porous media.
- Allows the gas to dissolve in the other two phases, but no oil is allowed to enter in the gas phase.
- It can model natural depletion and most secondary recovery processes.



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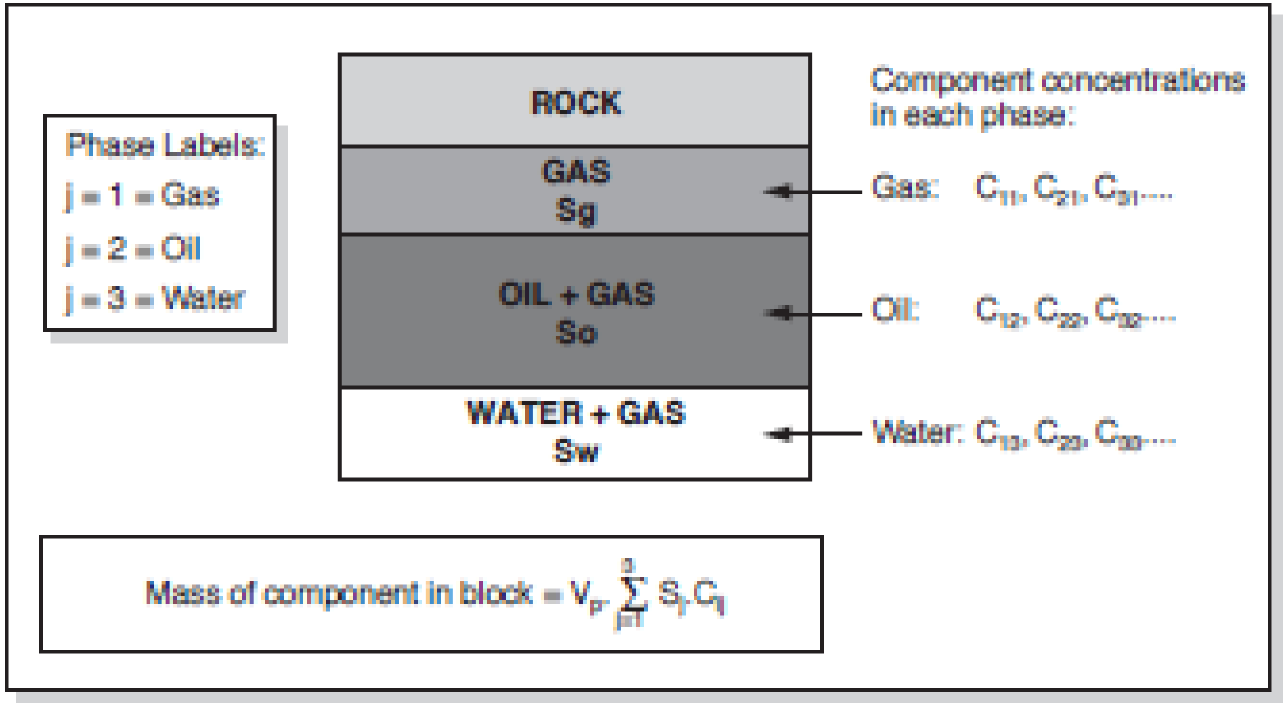
Composition model

- Compositional model is a model which explicitly acknowledged the actual compositions of oil and gas phases due to their complicated PVT behaviour



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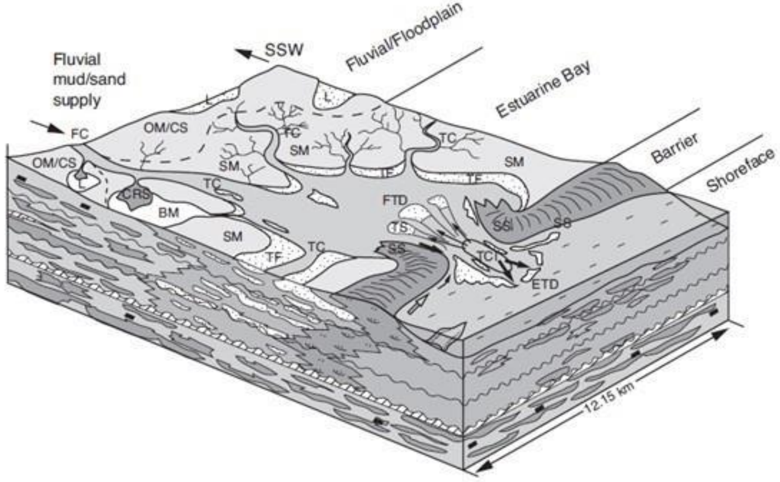
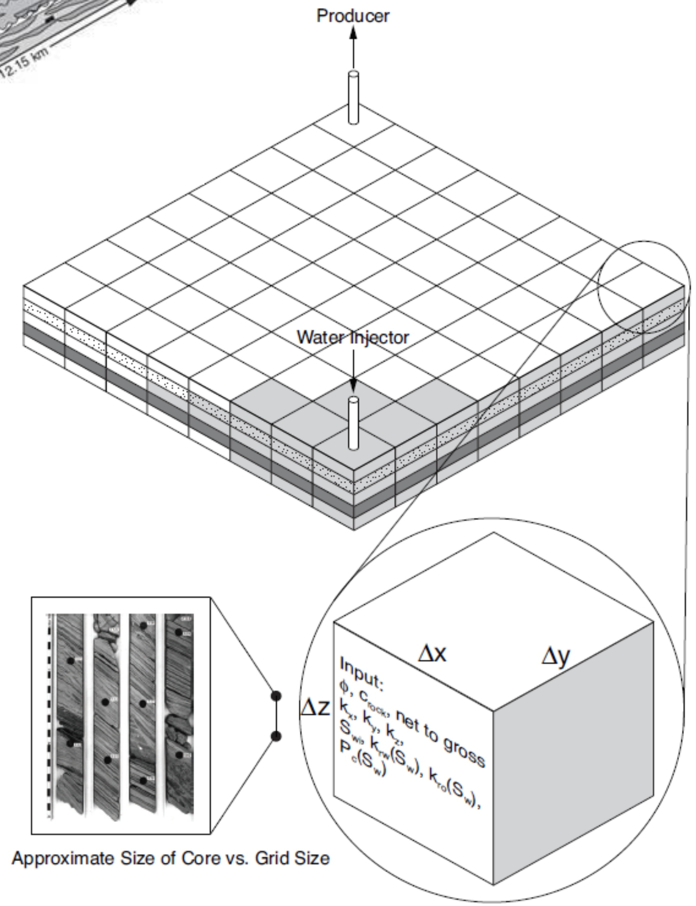
Reservoir simulation tasks



The process can be break down as:

- Choice and controls
  - Locations of producers and injectors
  - Well completion and down hole equipmer
  - Water or gas injection rates
  - The production rate
- Reservoir data
  - Reservoir geology
  - Drive mechanism, is there any aquifer
- Reservoir performance results:
  - Well production rates of oil, water and gas
  - Field reservoir pressure
  - Individual wells pressures and PI



Build and run a reservoir simulation model

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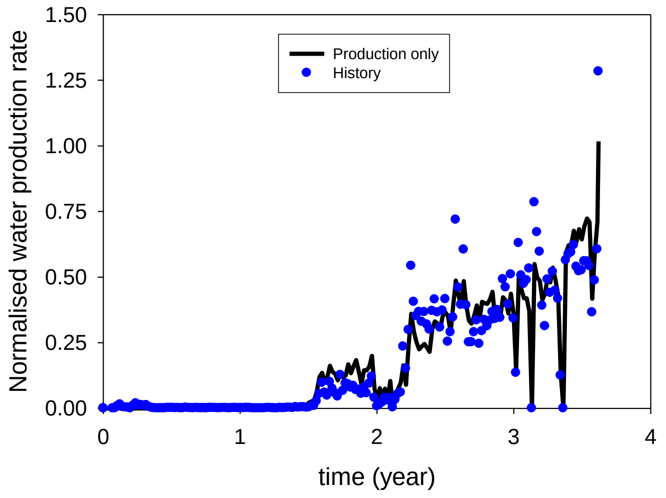
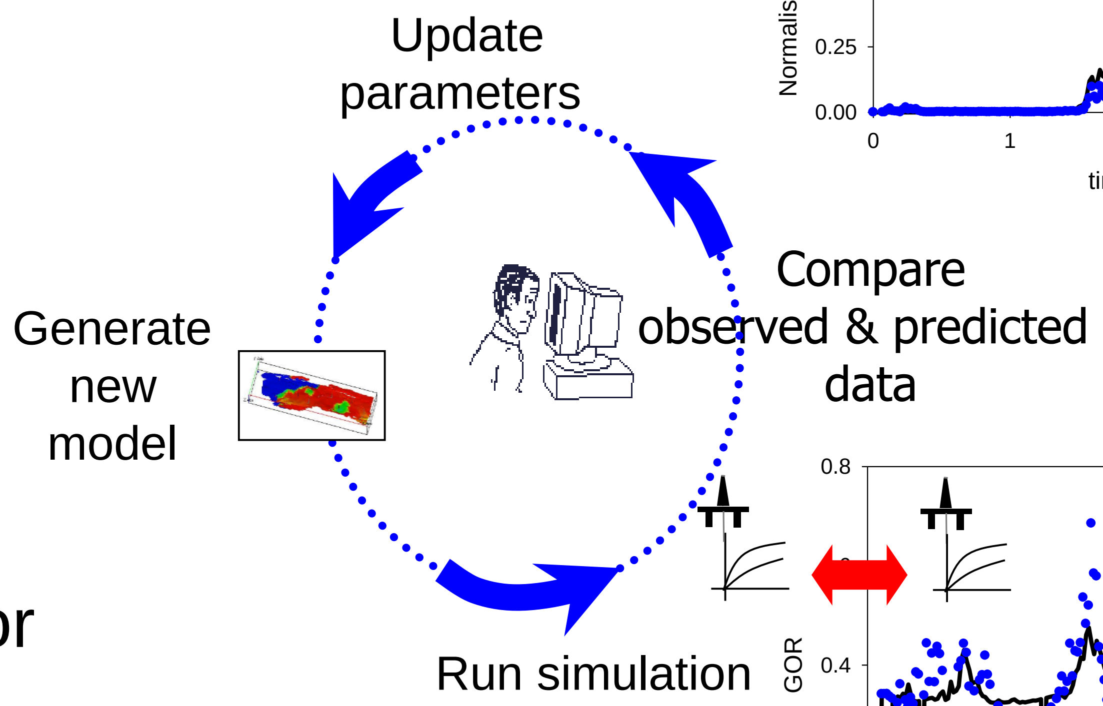
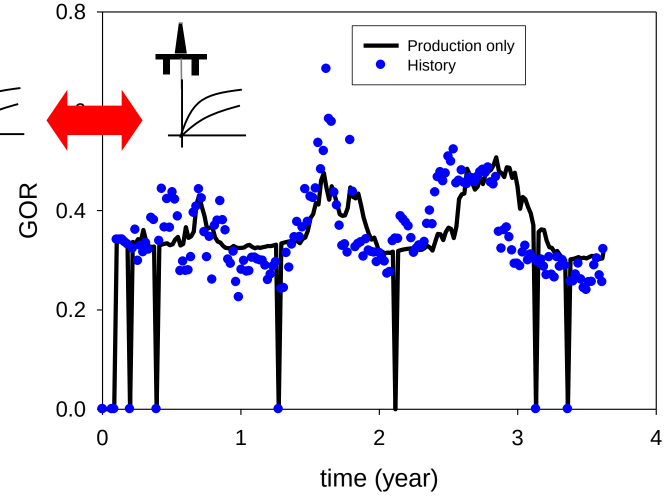
- Gather and input the rock and fluids data (reservoir description)
- Choose certain numerical features of the grid (number of cells, cells size, etc)
- Setup the correct field wells controls (injection rates, bottom hole pressure constrains, etc). This *drives* the model.
- Choose which output you would like to have printed to file you can then plot later. The outputs can include
- The average field pressure as a function of time
- Total field cumulative of oil, water and gas over time.
- Individual well pressure (bottom hole, well head pressure)
- Spatial distribution of oil, water and gas saturations

What is history matching?

- Adjusting the simulator input in such a way as to achieve a better fit to the actual reservoir performance.
- The changes in the simulation model should most closely reflect the changes in the understanding of the field geology.
- The field and individual wells cumulative productions, water cuts and pressures are those for matching







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Prediction with uncertainty

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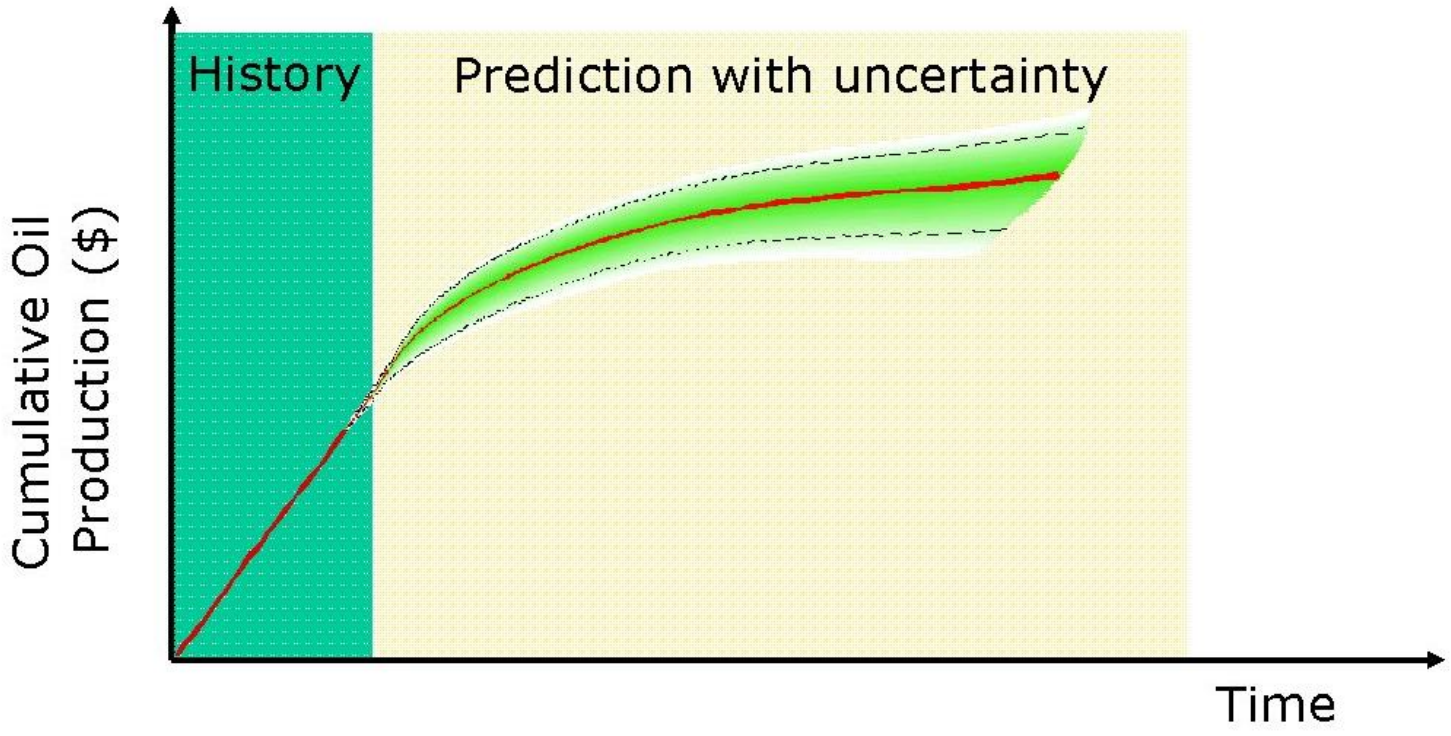
“If a man will begin with certainties, he shall end in doubts, but if he will be content to begin with doubts, he shall end in certainties.“

Francis Bacon



Uncertainty handling

Possible sources of error can be

- Inaccuracies in the size of the reservoir, areal extent, thickness, net to gross.
- Lack of knowledge about reservoir architecture, sand bodies, facies distribution, shales, faults, etc.
- Uncertainties in the numerical values of rock properties (porosity and permeability).
- Inaccuracy in the fluid properties like viscosity and FVF.
- Lack of sufficient data.

Reservoir simulation model

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- *“Is a grid block model of a petroleum reservoir where each of the blocks represents a local part of the reservoir. Within a grid block the properties are uniform although they might change with time as the reservoir process progresses. Blocks are generally connected to neighbouring blocks so fluids flow in a block to block manner. The model incorporates data on the reservoir fluids (PVT) and the reservoir description and their distribution in space.”*

Field applications

- Reservoir simulation may be applied at any stage at the early, middle or late field lifetime:

Appraisal stage: reservoir simulation can be used to design the overall field development plan, in terms of:

- The nature of recovery mechanism (natural depletion, waterflood, gas injection)
- The nature of facilities required to develop the field (platform, subsea development tieback, etc)
- The nature and capacities of plant, compression capacity, separation capacities.
- The number, locations and type of wells.
- The sequence of wells drilling.

Field applications

- Reservoir simulation may be applied at any stage at the early, middle or late field lifetime:
- Mature field development: it has been production for some time but there is still a reasonably long life ahead for the field. At this stage reservoir simulation is a tool for reservoir management which allows the reservoir engineer to plan and evaluate different development options The engineer now has some production history, pressures, cumulative oil, water cuts and GOR’s. at this stage typical simulation activities are:

Field applications

- Mature field development (cont…)
- History matching in order to obtain a better tuned reservoir model.
- Using the history match to re-visit the development plan (infill drilling, injection capacities, etc).
- Review the reservoir recovery mechanism, better understating of the reservoir physics.
- Decide among smaller projects like “attic” drilling.

Field applications

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- Late field development: defined as the closing few years of field production before abandonment. Is it worth to study the reservoir any further??? Assess new options in the development plan that can give a “new lease of life” to the reservoir. i.e. new drilling technology, stimulation campaign, IOR implementation.

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Thank you