TPG4160 – Reservoir simulation, Building a reservoir model

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Overview

Plan for the lectures

- The main goal for these lectures is to **present the main concepts** of reservoir models and reservoir model building
- Proposed literature: *Philip Ringrose and Mark Bentley “Reservoir Model Design A Practitioner’s Guide” Springer 2015*

What is reservoir modelling?

- The role of reservoir modelling is to summarize as much as possible of our **collective qualitative and quantitative knowledge** about the reservoir in order to give **quantitative answers** to questions related to reservoir development and reservoir management.
- The products of of reservoir modelling may be
  - Knowledge databases
  - Parameterized recipes for creating digital representations of the sub-surface (models)
  - Digital representations of the sub-surface (model realizations)

Classification of models – Based on purpose

- Asset optimization
- Field development
- Long term production optimization
- Well planning and geo-steering
- EOR evaluation
- Data interpretation (Well testing, ...)

Classification of models – Based on scope

- Static model
  - Framework model
    - Fault pattern
    - Main horizons
  - Object model – Spatial distribution of **geological objects**
  - Fault-seal and barriers – Compartment communication
  - Property model – Spatial distribution of **properties**
    - Rock types
    - Porosity, Permeability, …
  - Contact model
- Dynamic model
  - Fluid model
  - Well model
  - Production strategy

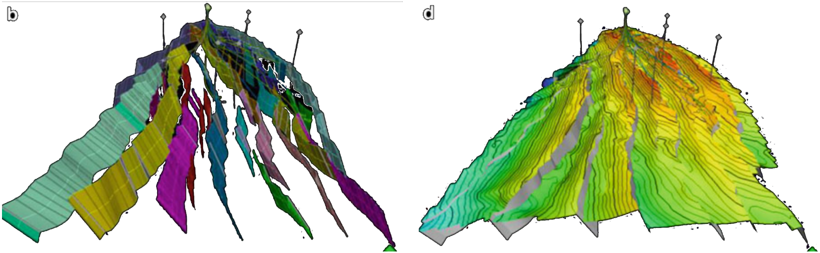
Software tools

- Data-management tools – Shared earth models
  - Databases
  - Work-flow managers
- Geo-modelling tools – Static model builders
  – Examples: Petrel, RMS
- Reservoir simulators
  – Examples: ECLIPSExxx, Intersect (IX), Tempest MORE, tNavigator
- Asset simulators
  – Example: Pipe-it

Framework model and compartment communication

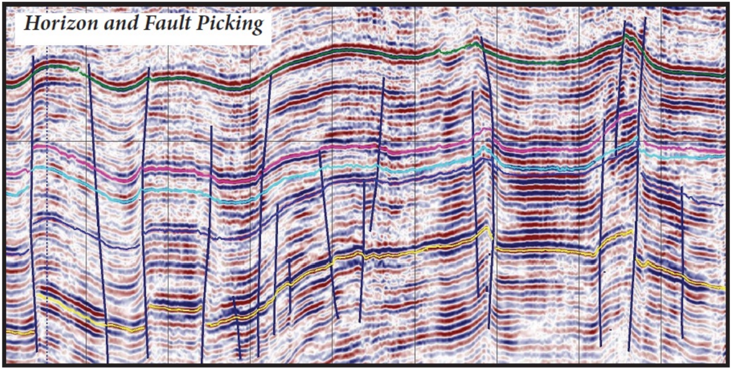
What is a framework model?

- The framework model consist of the main faults and zone boundaries.



Sources for framework model

- Seismic is the main data source
- Well-picks of faults and zone boundaries are used for anchoring seismic data (in the “time” domain) in space.
- The seismic interpretation is used as the starting point for model building

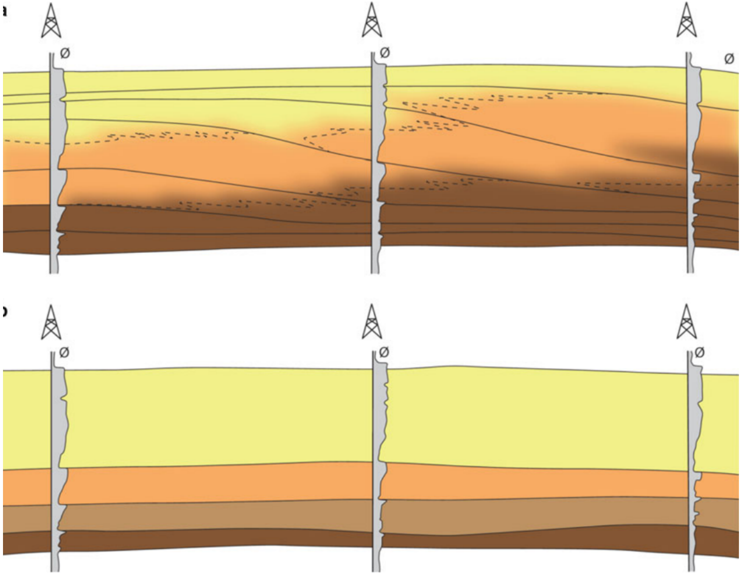


Source http://www.enageo.com/seismic_interpretation.html

Important points

- Most modern model work-flows demand that the framework model is consistent and “water tight”
- Seismic has poor vertical resolution and seismic data are degraded near faults.
- Faults with throw $\lesssim 10m$ (at best) are invisible on seismic
- Seismic reflectors does not necessarily coincide with zone boundaries
- There are more zone boundaries than reflectors. Additional zone boundaries and vertical barriers are found on well-logs

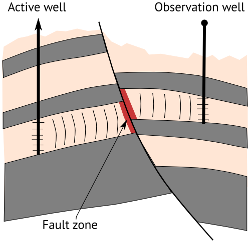
Chrono-stratigraphy vs. litho-stratigraphy

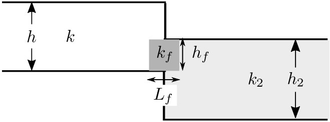


Compartment communication

- The framework model is built with two main goals:
  - Define a set of (non)communicating **compartments**
  - Define a reasonable zonation for geological modelling (object model)
- Inter-compartment communication is the 0-th order dynamic model.
  - In gas reservoirs and high permeable reservoirs a mass-balance model with compartments as smallest unit is often sufficient
- Inter-compartment communication is often the largest uncertainty in the reservoir description
  – Dynamic data is the main source of information for reducing this uncertainty

Representing compartment communication on a grid





Source: `http://folk.ntnu.no/perarnsl/Literatur/lecture_notes.pdf`

- The communication is influenced by the altered permeability at zone boundaries and fault planes
- The altered zone is to thin to be represented explicitly in the grid and is modelled as a plane with characteristic property

$$\beta_f = \frac{k_f}{L_f}$$

Transmissibility multipliers

- In the two-point flux approximation the communication between grid-blocks is represented as transmissibilities (T_{ij})

$$\frac{1}{T_{ij}} = \frac{1}{T_i} + \frac{1}{T_j} = \frac{1}{A_{ij}} \frac{k_i L_j + k_j L_i}{k_i k_j}$$

- In most reservoir simulators the barriers (β) are input as transmissibility multipliers

$$M_{ij} = \frac{\beta_{ij}}{\beta_{ij} + \frac{k_i k_j}{k_i L_j + k_j L_i}}$$

- Transmissibility multipliers are **grid dependent**

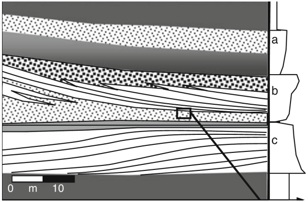
Object model

Conceptual model

- The conceptual model is the basis for all reservoir modelling
  - A mental image shared by everyone involved
  - Sketches of reservoir sections are highly informative and brings clarity to the mental image
- Questions to address:
  - What are the fundamental building blocks
    - These building blocks are called **model elements**
  - What is the general shape of these model elements
  - How do these model elements stack up in space
- Selection of model elements is not a job for geologists alone
- Single- and multi-phase **flow properties** are very important when selecting model elements

Geological objects

- The objects in the geological object model are associated with the model elements in the conceptual model
- The reservoir zones and sub-zones are model elements
- Model elements usually form a **hierarchy of model elements**



- The spatial distribution of model elements within a zone may be generated by “object modelling”, but it is part of a geological object model independent of the algorithm used

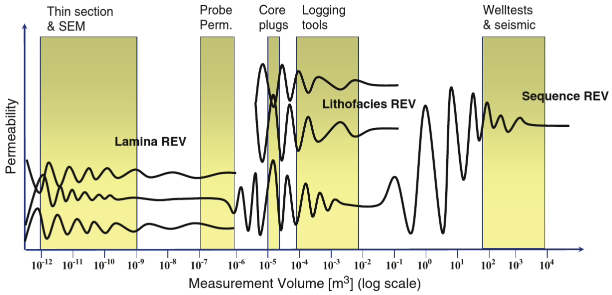
Property model

Model elements

- The geological objects (model elements) have **property fields**, that is properties defined everywhere in space inside the object
- Properties are **modelled on a grid**
  – This implies that the objects are **sampled on a grid**
- For simulation, model element properties should be **slowly varying** between grid-blocks
  – Sadly this is often not the case is many simulation models used in the industry today
- There should be a close connection between model elements and the “rock-types” used for assigning multi-phase properties

Representative elementary volume REV

- Properties such as permeability are scale dependent, and only exist in specific scale ranges known as REV scales.



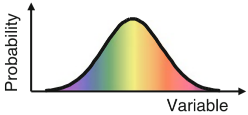
- Ideally we should have (Separation of scales)

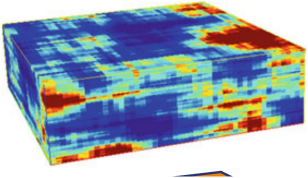
$$\text{Grid block size} \ll \text{REV} \ll \text{Object size}$$

This is usually impossible to obtain in practice

Data conditioning

- Properties are usually modelled using voxel based geo-statistics
  - Example: Gaussian field with a given spatial correlation structure (Variogram)





- Using such methods it is easy to condition to data from well-logs by keeping (the observed) values fixed
  - Due to the scale difference between the well-log observation and the property REV, this hard conditioning may be to restrictive. Alternative "soft conditioning" is usually more correct, but is surprisingly seldom used.
  - Permeability is not measured by well logging tools, and conditioning to well-log permeability is not correct.

Which properties to model

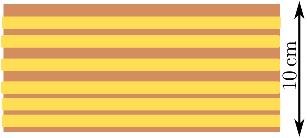
- The properties the simulator sees are
  - Porosity φ
  - Permeability k_v and k_h
    − Alternatively often input as k_h and $\frac{k_v}{k_h}$
  - Net to gross ratio (The use of NTG $\neq 1$ is discouraged !!)
  - Rock type numbers
    (These numbers may be used in conjunction with endpoint scaling in which case the model also have endpoint values in each grid-block)
- Apart from φ it is actualy often not a good idea to model these directly in the geological property model.

Upscaing of properties

- Reservoir modelling always involve upscaling of properties.
- **Geological upscaling:**
  - Incorporating measurements on smaller scales and geological knowledge in order to obtain model element properties and property correlations
  - Conditioning data (Well-logs)
  - Multiphase properties (Relative permeability)
- **Grid based upscaling:**
  - Calculating properties in a coarse grid reservoir simulation model based on a finer grid geological model.

Geological upscaling – Simple example

- At small scales a model element comprise a layered structure of sand and mud with variable sand fraction.



- Average porosity is available in well-logs
- Measurements on core material give

	Porosity	Permeability (mD)
mud	0.15	1
sand	0.30	900

- Which property to model?
- What is the (upscaled) porosity and permeability in the model element?

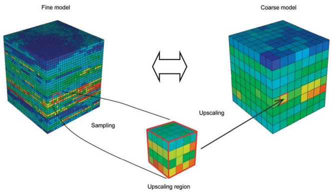
Simple example continued

- The spatial distribution of fraction s is modelled using geostatistics
- The measured porosity data at wells are transformed to sand fraction

$$s = \frac{1}{0.15}\varphi - 1$$

- Porosity: $\varphi = 0.15 \cdot s + 0.15$
- Horizontal permeability: $k_h = (899 \cdot s + 1)$ mD
- Vertical permeability: $k_v = \frac{900}{900 - 899 \cdot s}$ mD
- What about relative permeability?

Grid based upscaling



Source http://www.epgeology.com/static-modeling-f39/how-upscale-permeability-t6045.html

- Porosity is found by bulk volume weighted arithmetic average
- Saturation is found by pore volume weighted arithmetic average
- Permeability is found by solving local flow problems with suitable boundary conditions (flow based upscaling)
- Assigning rock types and corresponding upscaled multiphase properties (relative permeability) is problematic in many cases

The simulation box

- The geological object model and property model is modelled in an **unfaulted and uncompacted rectangular** coordinate system conventionally known as the simulation box
- Property values are in most tools moved to block values in the actual gridded framework model using direct ijk-correspondence
  – This infer severe **restrictions on the grids** that may be used for gridding the framework
- An alternative and potentially more correct transformation, GeoChron, is used in some tools

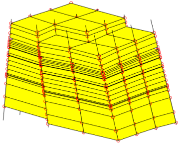
Grids for reservoir simulation

Implications of the two-point-flux approximation

- K-orthogonality
- Grid orientation effect

Cornerpoint grid — Pillar grid

- The cornerpoint (or pillar) grid is a legacy grid format that is supported by all reservoir simulators
- The most widely used grid type and in many companies the only type in official models
- The grid has 8-corner grid-blocks
- Corners are defined on pillars

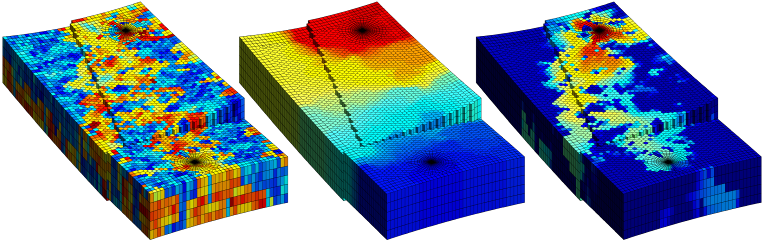


https://www.sintef.no/projectweb/mrst

- Major weak points:
  - Grid refinements
  - Fault representation
  - Complex well paths

2D Voronoi grid

- Voronoi grids have n-corner grid-blocks where n may vary
- Corners are defined on pillars



Source https://www.sintef.no/projectweb/mrst/gallery/flexible-gridding/

- Major weak points:
  - Non areal Grid refinements
  - Complex well paths

Unstructured grids

- Unstructered grids have any shape grid-blocks
- Blocks often of Voronoi type
- Major weak points:
  - Sampling−Upscaling from geo-model
  - Missing K-orthogonality (if not accounted for in the voronoi definition)

Implications of geo-grid – simulation-grid compatibility