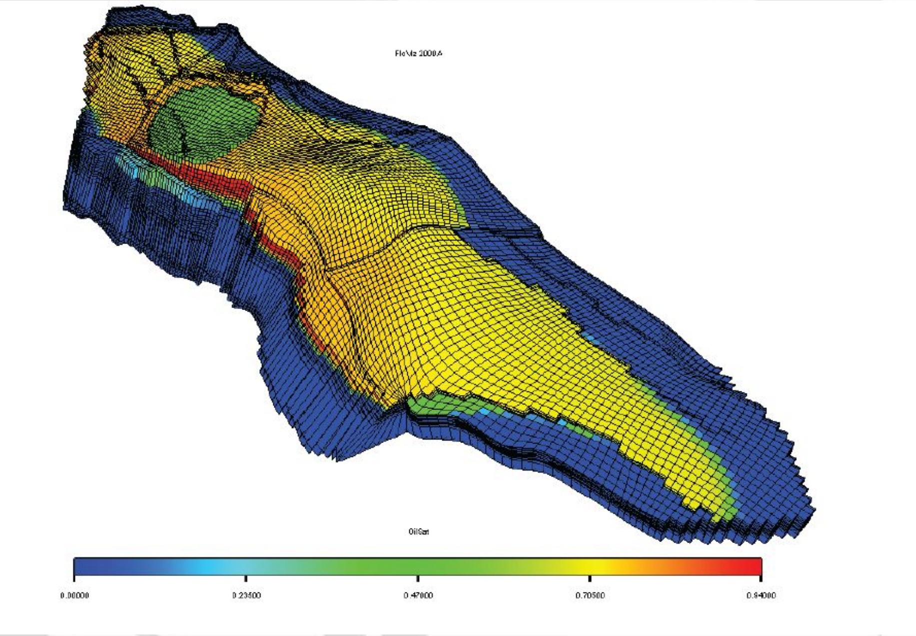
Reservoir Simulation



Chapter-one

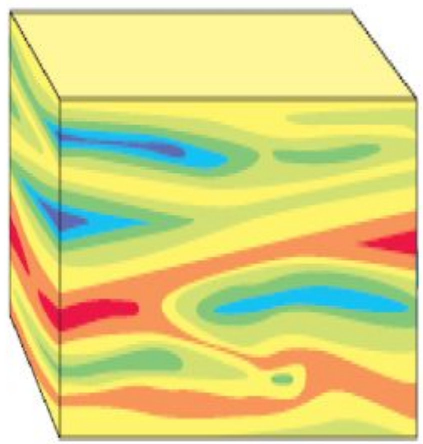
Introduction

THE CHALLENGE OF RESERVOIR SIMULATION …

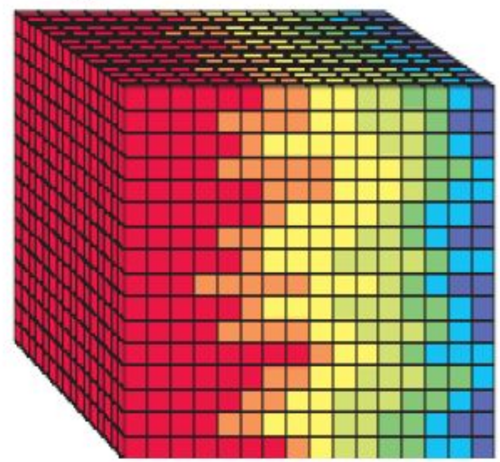
- Simulation means to imitate the behavior of a reservoir in terms of production pressure and production rates as a function of time by using a reservoir model

Real Reservoir

Reservoir Model



Dynamic Reservoir Model



DYNAMIC RESERVOIR SIMULATION

Early in a fields life, it is essential to be able to evaluate how much Hydrocarbons will be produced through time:

- How much hydrocarbon is in the reservoir ?
- How much of that hydrocarbon can potentially be recovered ?
- How quickly can the recoverable hydrocarbons be produced ?
- How will the reservoir perform under various development scenarios ?

A Dynamic Reservoir Model is a useful tool that may help to answer those questions.

Incentives for running a flow simulation

- **Appraisal**
  - To identify dynamic incertitude
  - To define appraisal needs (contacts, faults, facies variations)
- **Non producing reservoir**
  - To identify efficient recovery mechanisms
  - To define the well number and their architecture
  - To optimise Capex
- **Producing reservoir**
  - To integrate all history production data
  - To improve reservoir description
  - To optimise oil production and recovery
- **In all cases**
  - **To establish reliable production forecasts.**

Computer Modeling

- **The reservoir model** Fluid flow Equation within the reservoir
  The reservoir is modeled by subdividing the reservoir volume into an array, or grid, of smaller volume elements, which called: gridblock, cell, or node.

- **The well model** Fluid flow that represents the extraction of fluids from the reservoir or the injection of fluids into the reservoir

- **The well bore mode** Fluid flow from the sand face to the surface

- **The surface model** constraints associated with surface facilities, such as platform and separator limitations

Reservoir simulator

1 Reservoir Simulation Model

=

1 Numerical calculator

+

1 Set of modelled data

Reservoir simulation model

1 Numerical calculator:

- Flow equations are mathematical expression adapted for computer treatment

  => implies : ***dicretization***

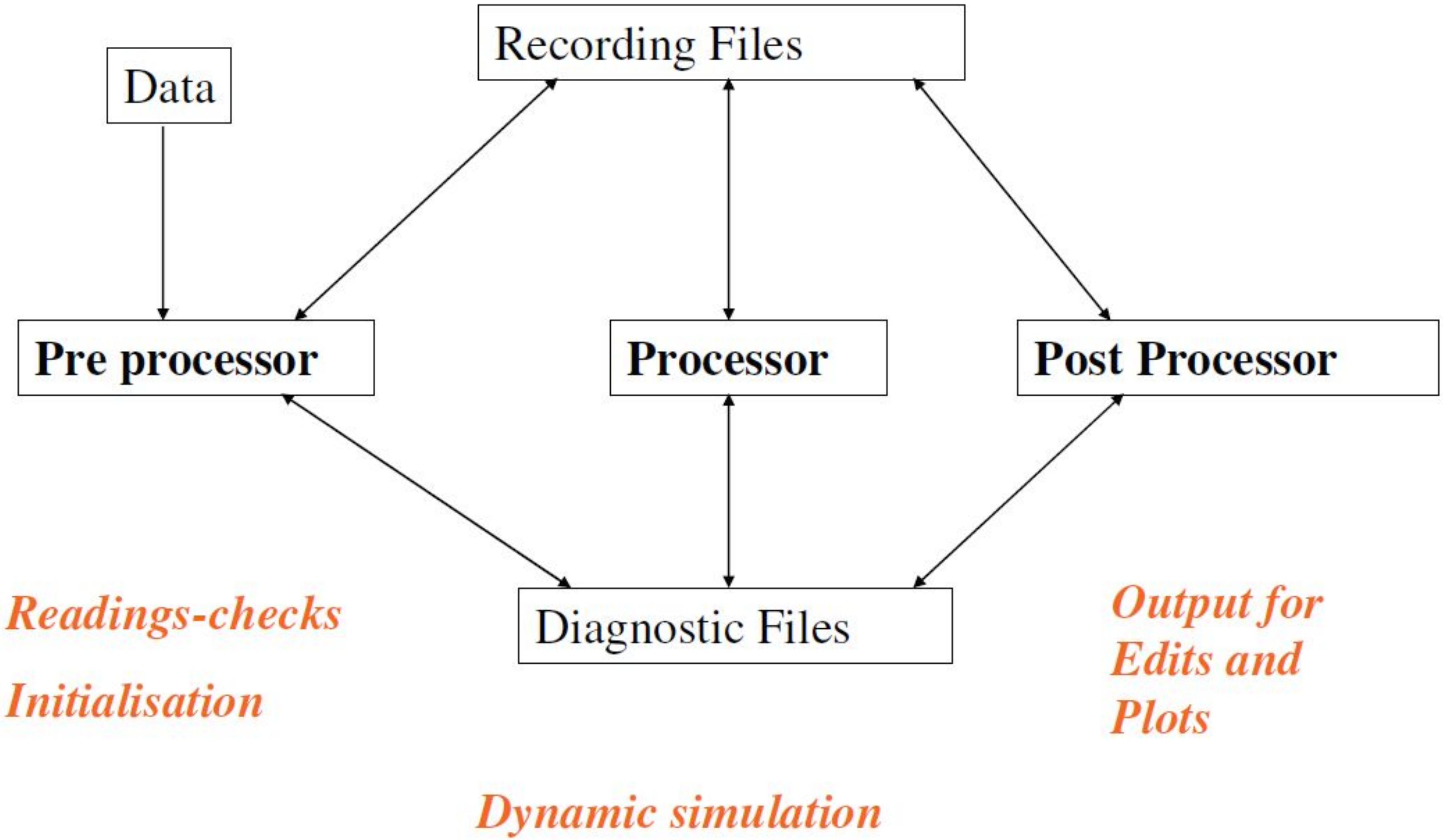
- Main simulations models:

→ **Black Oil** -Fluid compositions constant-Most reservoirs

→ **Compositional** -Variable fluid compositions - Gas condensate reservoir or volatile oil

→ **Double Porosity** -Geometry adapted to Fractured reservoirs

Reservoir simulation model



Main modeled phenomena

- Reservoir properties
- Fluid properties (in reservoir conditions)
  - Liquid vapour equilibrium
  - Compositions
  - Density, viscosity
  - Compressibility

  } for each phase
- Flow (in reservoir conditions) :
  - Permeability
  - Relative permeability and capillary pressure
- Material balance (in each cell)

Definitions

- **Modeling:**

  building the model
  (define parameters through Integrated reservoir characterisation studies, choose physical options)

- **Simulation:**

  running the model, either in history matching simulations or in forecast simulations

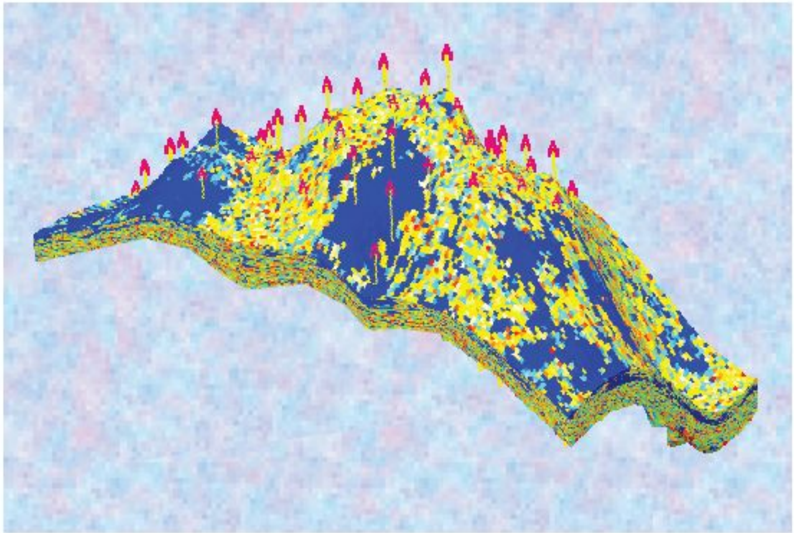
Types of models

- **There are several types of numerical simulator:**
  - Black-oil simulator : One porous medium + black-oil functions
  - Compositional Simulator : One porous medium + EOS
  - Dual porosity Simulator : Two porous mediums (matrix and fractures)
  - Thermal Simulator : Pressure + Temperature equations.

- **A Numerical simulator also integrates specific features such as:**
  - Grid Geometry (1D, 2D, 3D, corner point geometry, …)
  - Pressure drops through tubings and surface network.
  - Well schedule.
  - Numerical schemas (discretisation of equations).
  - Resolution methods (resolution of equations).
  - Time step management.

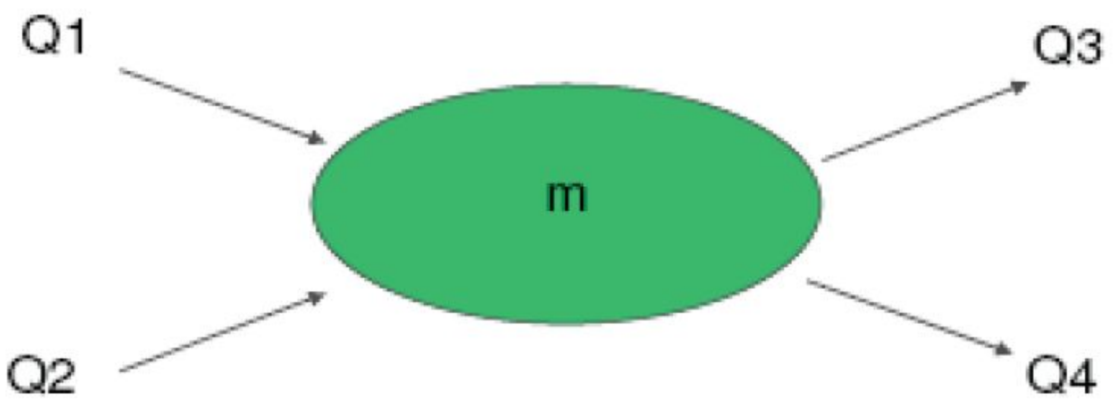
Types of simulators

- Mass balance simulator (ex MBAL)
- Numerical simulator
  (ex ATHOS, ECLIPSE, VIP....)
  - Single phase
  - Black Oil
  - Compositional
  - Chemical
  - Thermal
  - Fractured



Types of simulators

- **Material Balance Equation**



$$Q1 + Q2 + Q3 + Q4 = \Delta m$$

Flow Term = Accumulation Term

Black Oil model

- **Black-oil simulation means that the fluid properties depend only on pressure. They do not depend on the composition of that fluid.**

  - Simplified fluid description PVT – (Black Oil)
  - Reservoir rock properties / Petrophysics (K, ∅, C_p)
  - SCAL (Kr - Pc)
  - Boundary conditions : wells and aquifers
  - Initial reservoir condition

NUMERICAL MODELS: DISCRETIZATION

❑Space discretization:

- Grid geometry (sugar box, corner point, …)
- Grid definition and cells dimensions
- One value per grid for each data
- Calculation of flow transfers between cells.
- Compressibility

❑Time discretization:

- Time step definition
- Calculation of production data per time step.Permeability
- Calculation of reservoir data at the end of time step taking into account constant production data and constant reservoir data during the time step.

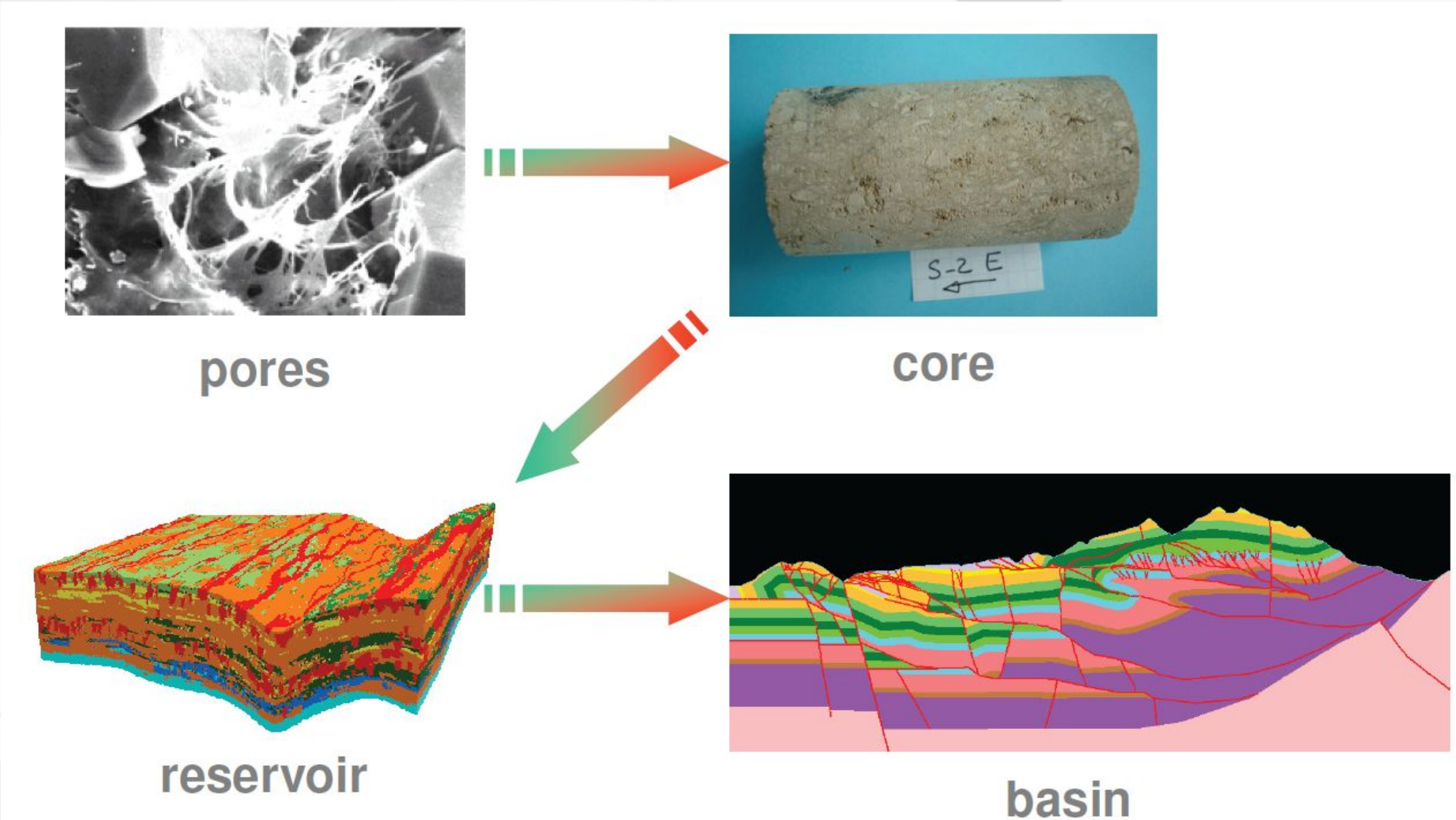
❑Simulation costs increase more rapidly than the number of cells as

- Calculation per time steps are proportional to the number of cells
- Time step decreases with the cell dimensions

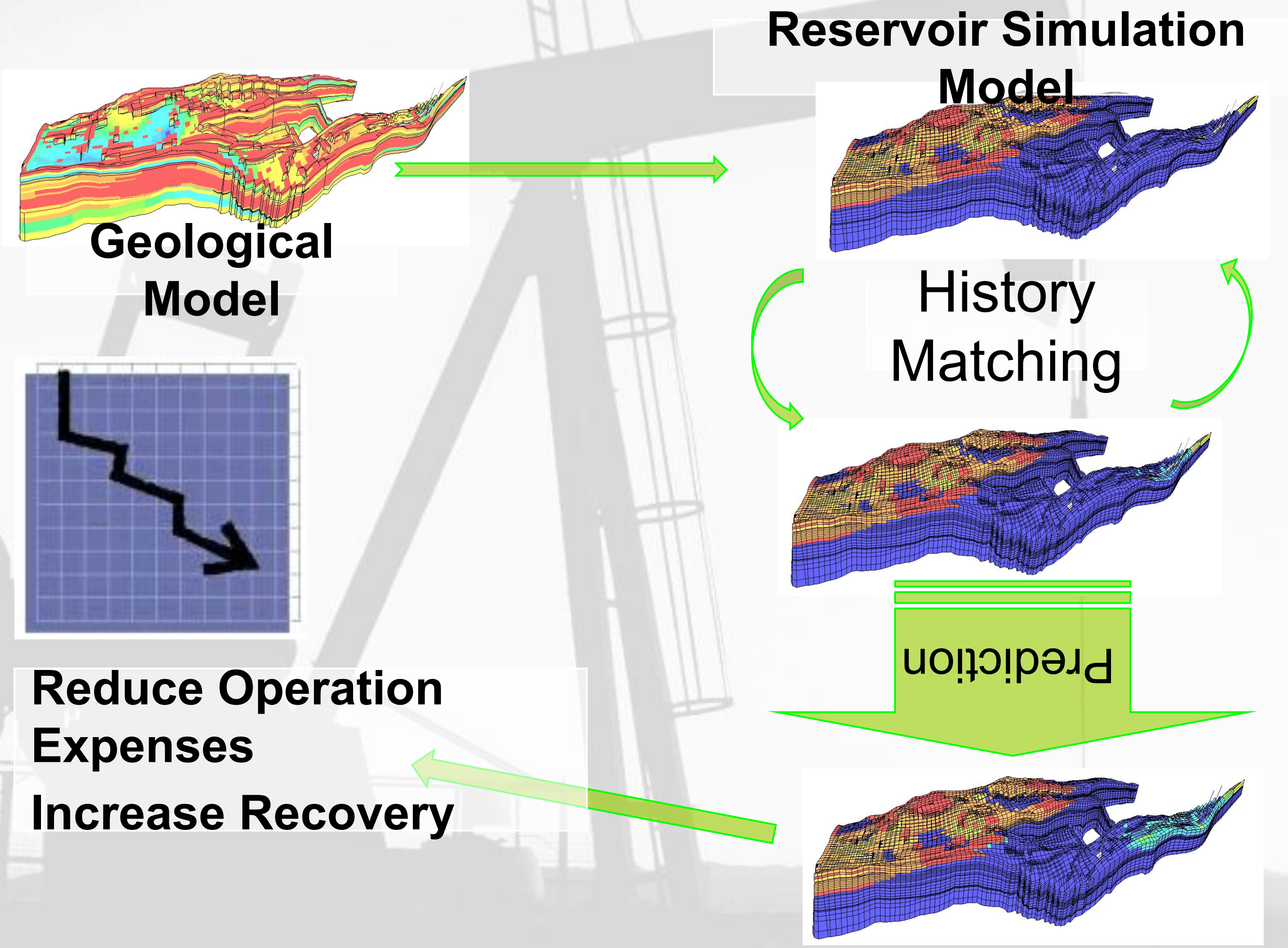
Reservoir Simulation PLANNING

- Reservoir simulation study duration : from weeks to years
- Necessity to plan carefully the study to give correct results in time, before to take decisions for the field management :
  - *Problem definition*
  - *Data review*
  - *Data acquisition*
  - *Approach selection*
  - *Reservoir characterization – build geological static model*
  - *Upscaling to generate dynamic reservoir simulation model*
  - *Computing support*
  - *Initialisation*
  - *History matching*
  - *Prediction*
  - *Reporting*

A question of Scale



Prediction Future performance



Problem definition

- Determine present reservoir performance and associated
  operating issues in order to define future performance

  - Collect information
  - Identify the problems
  - Determine the objectives

Data review

- **Data generally must be reviewed and reorganized because :**

→ they come from several sources of information

→ the review evidences inconsistencies and gaps

- **The objective of data review is to :**

→ decide if the data quality is sufficient to conduct the study

→ plan data acquisition for the study purpose

Main Types of Data

TYPE	Geometry	Petrophysics	Fluids	Wells	Production
Description	Shape Thickness Dimensions Faults Contacts	Porosity Permeability Compress. Pc's Kr's S_{wi} S_{orw}	B_o, μ_o, … B_g, μ_g, … B_w, μ_w, …	Coordinates Completion PI	$Q_o = f(t)$ $Q_g = f(t)$ $Q_w = f(t)$ Separat. Cond.
Origin	Seismics Geology Well tests	Logs, cores Laboratory Tests	Laboratory Abacus	Well report Tests	Field

Study approach

- **What is the most suitable model to answer the problems :**
  - model dimensions (1D, 2D, 3D)
  - PVT type (Black oil, compositional)
  - Special physical options (double media, thermal, chemical …)

- **Factors influencing the study approach are :**
  - availability of simulators and computing environment
  - time, money and manpower

Study approach

- **Model design is influenced by :**
  - type of process to model
  - complexity in fluids mechanisms
  - objectives of the study
  - quality of data
  - needed level of details
  - budget

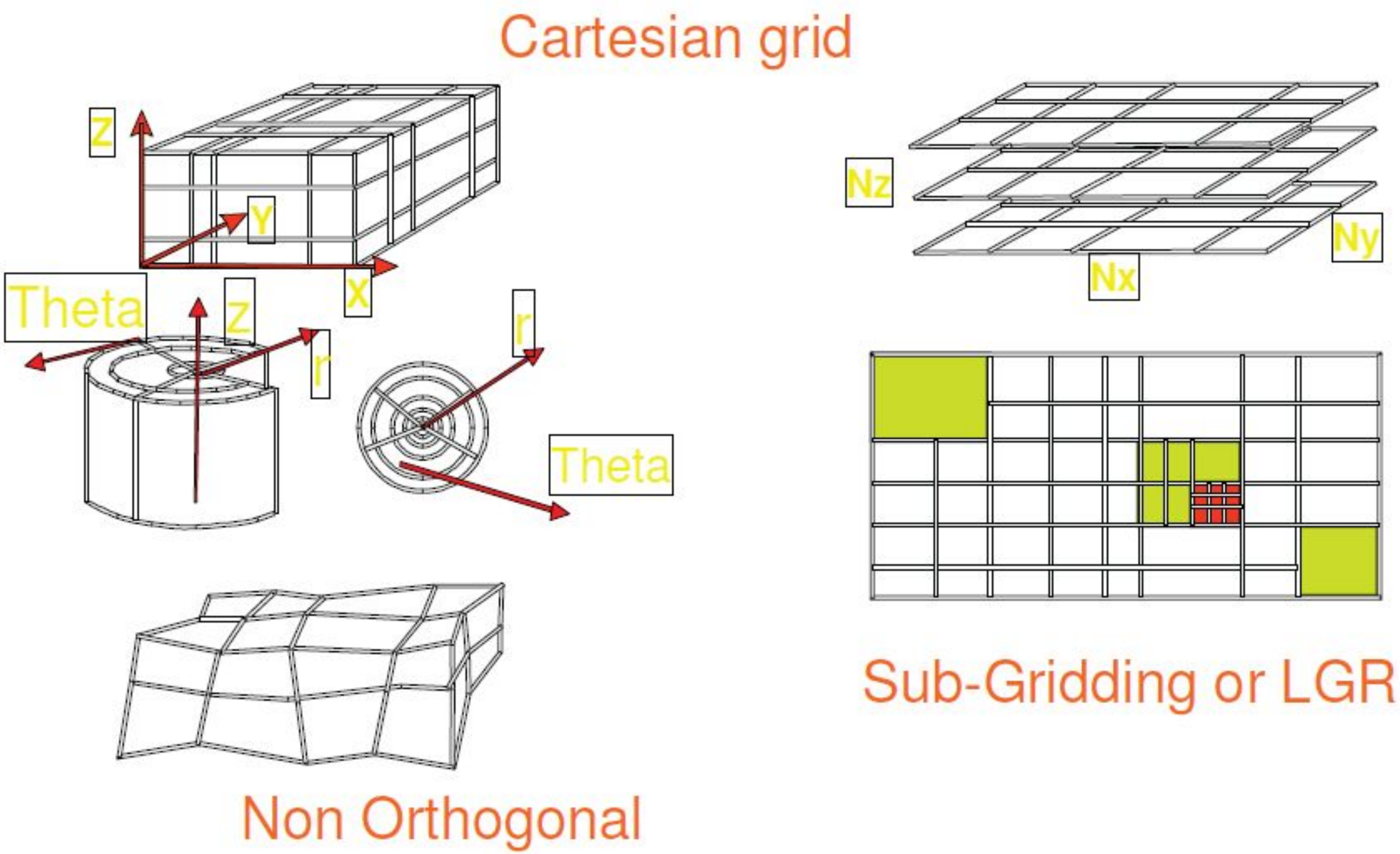
GRID TYPES

- **Grid may be defined in different ways which may give more or less facilities to describe the reservoir limits and discontinuities (faults).**

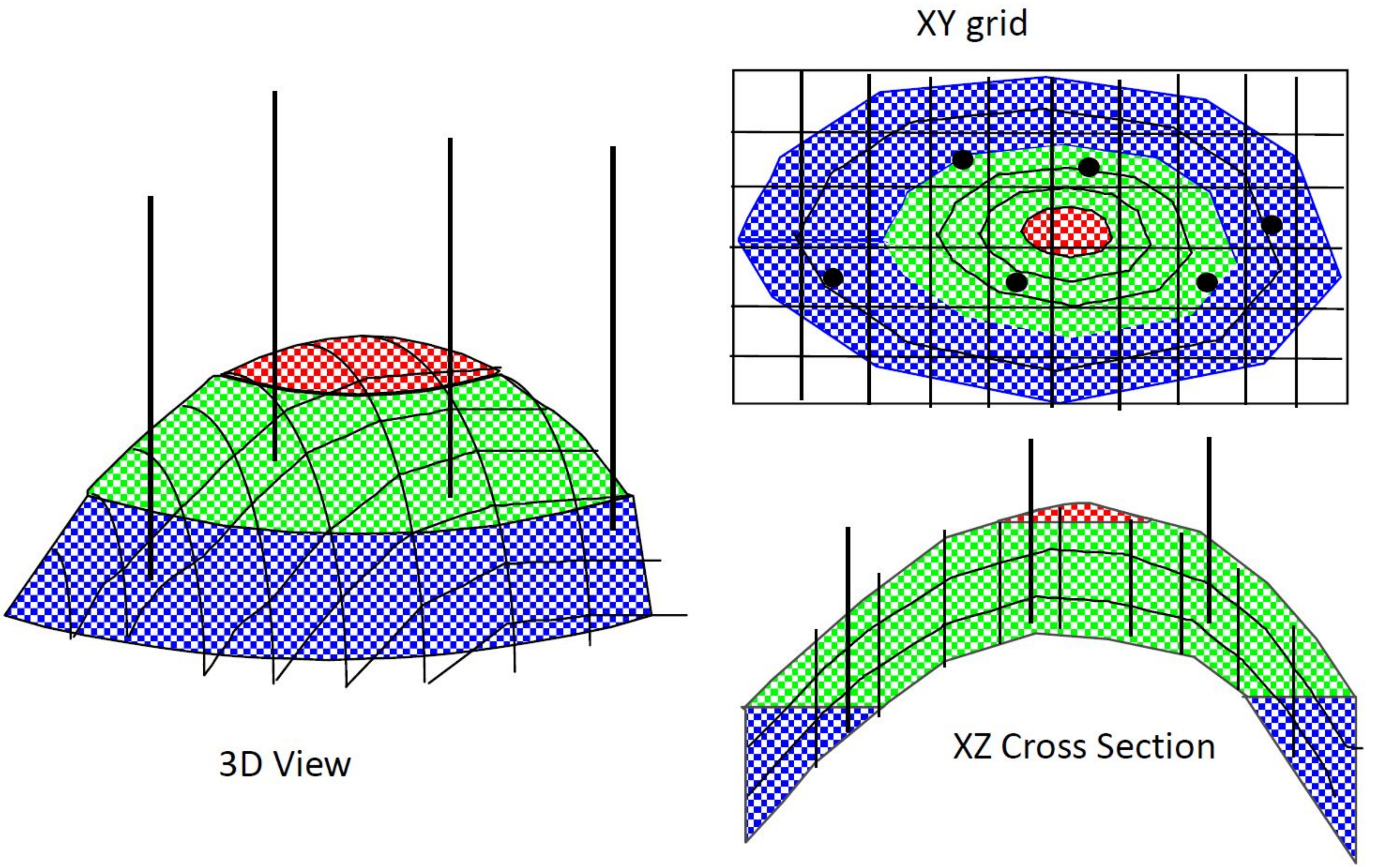
- **Flow equations are written in rectangular coordinates. (*If non orthogonal grid system is used equations should have to be corrected)***

- **Main grid types are:**
  - Conventional cartesian grid (x,y,z)
  - Sub-Gridding system
  - Non orthogonal grid (Corner Point Geometry)
  - Radial grid
  - Hybrid grid

GRID TYPES

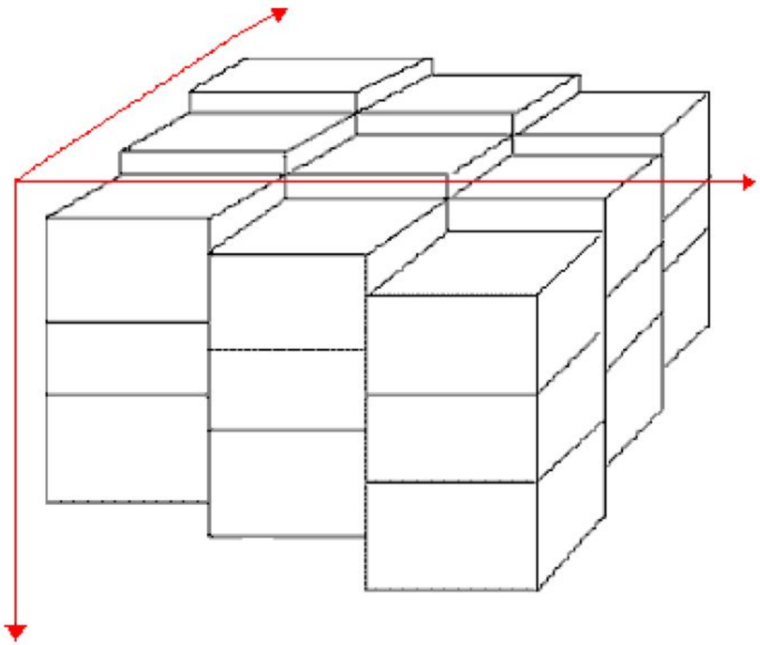

Cartesian grid
Z
Y
X
Theta
Z
r
r
Theta
Nz
Ny
Nx
Non Orthogonal
Sub-Gridding or LGR

Sugar box geometry

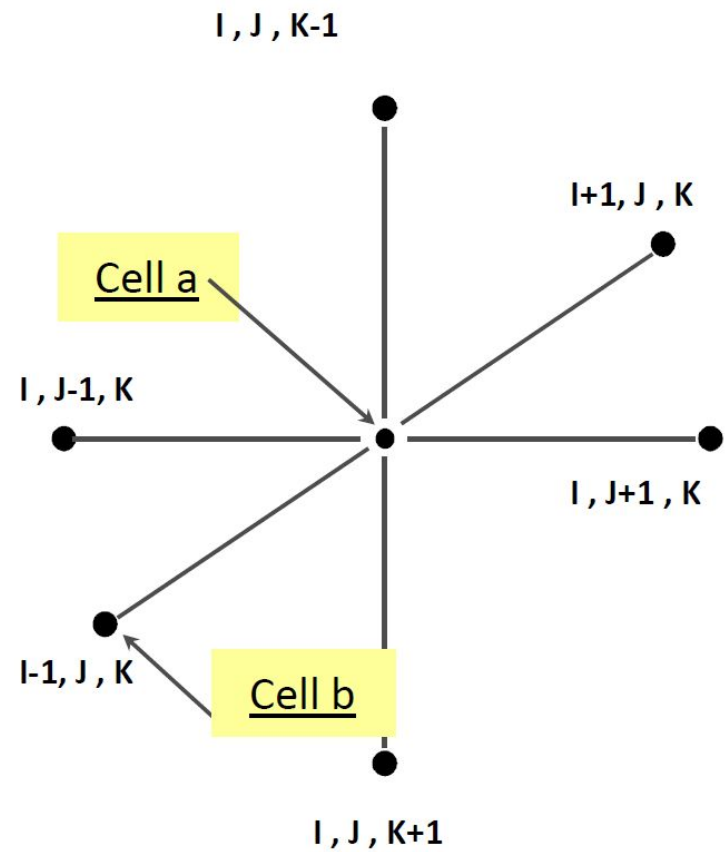


Sugar box geometry

3 main flow directions

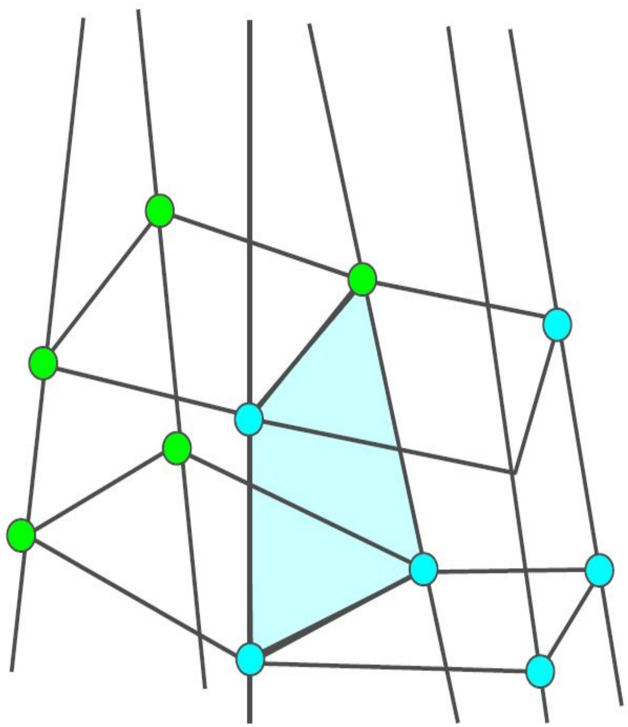


1 cell can communicate with 6 neighbours



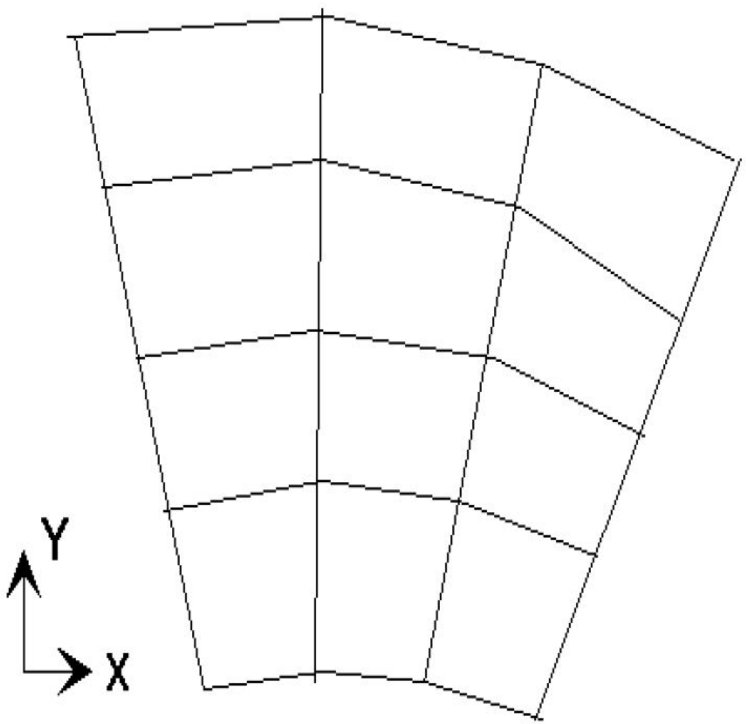
Corner point geometry

1 cell is defined by it's corners

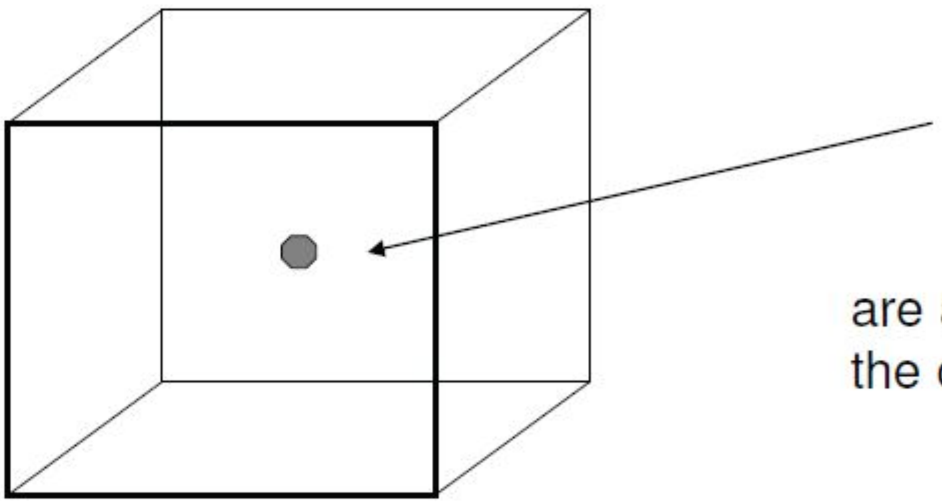


Pillar lines

Horizontal axis can have variable orientation



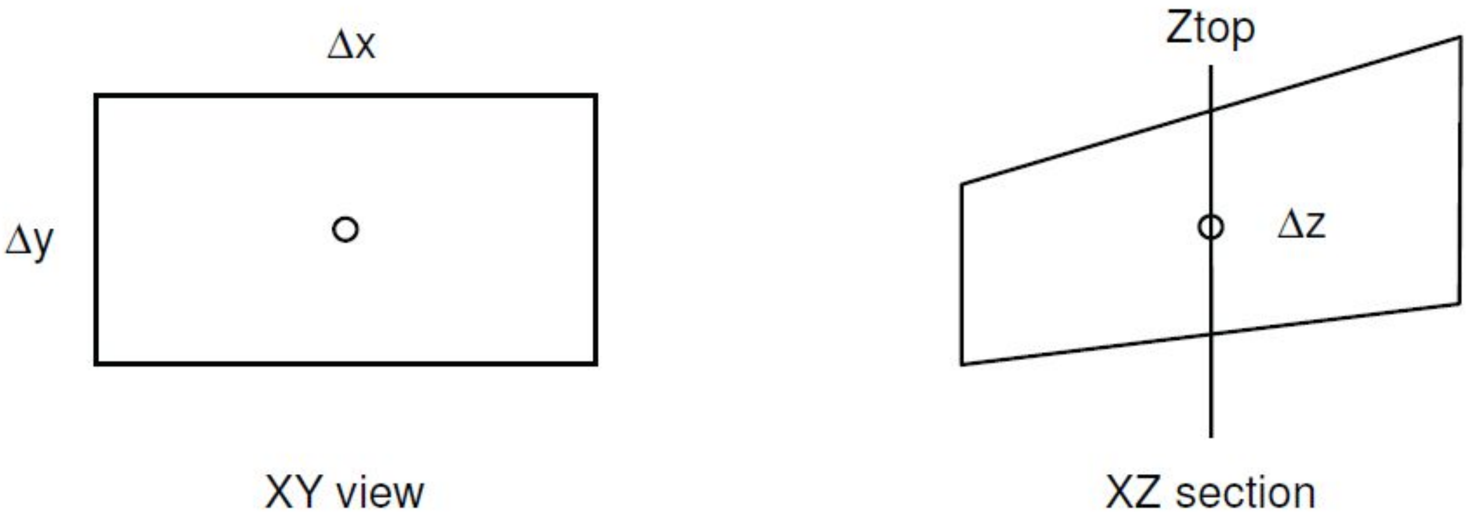
Reservoir description : PROPERTIES



Cell properties such as:
PORO,
PERMX,
PERMY,
PERMZ,
NTG,
are averages defined at the centre of the cell.

Reservoir description : PROPERTIES

Depths are defined at the grid block centre.

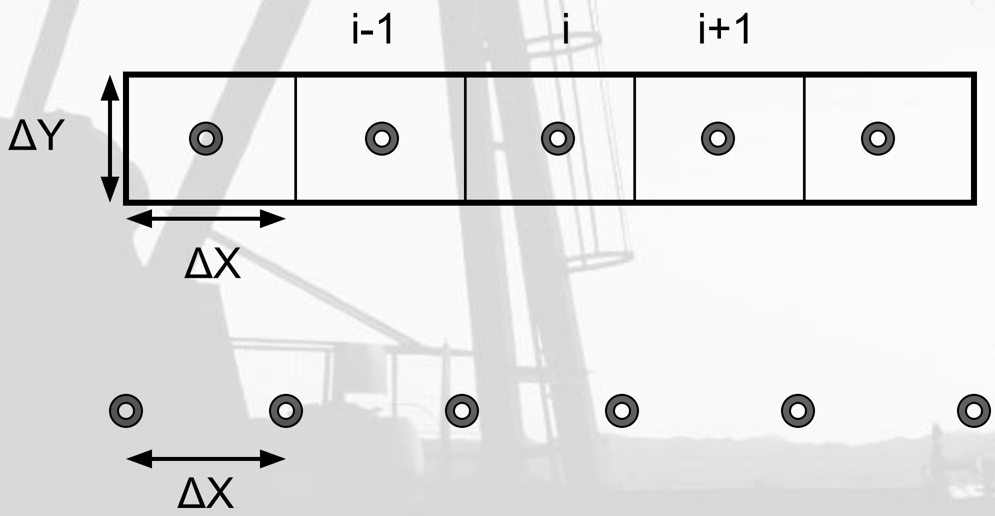


Cell volume is $Vt = \Delta x \,.\, \Delta y \,.\, \Delta z$

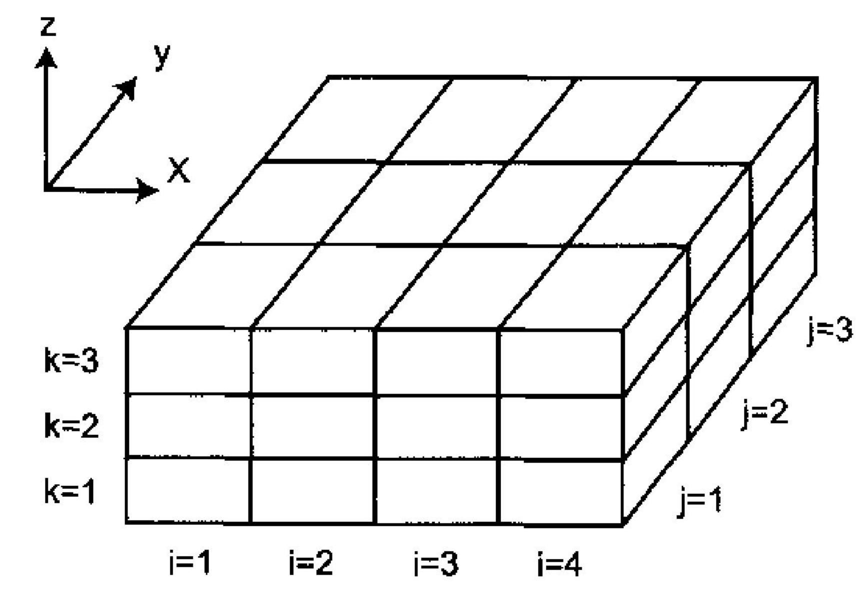
Reservoir Discritization

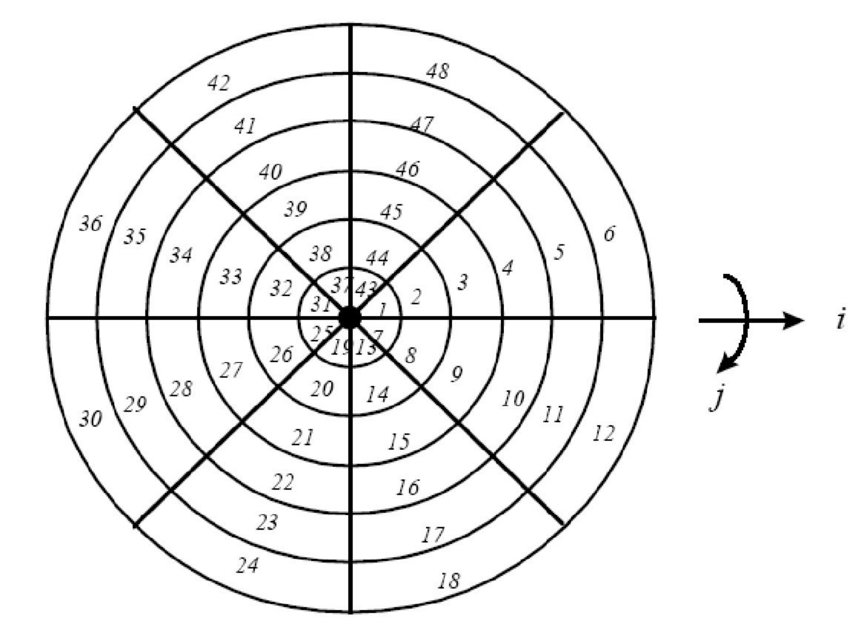
Defination: the reservoir is described by a set of gridblocks (or gridpoints) whose properties, dimensions, boundaries, and locations in the reservoir are well defined.

- ✔ Block centered grid
- ✔ Point distributed grid



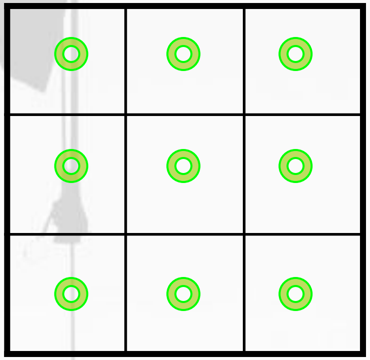
Block Identification and Ordering





Block Identification and Ordering

- Natural ordering
- Zebra ordering
- Diagonal D2 ordering
- Alternating diagonal
  D4 ordering
- Cycle ordering
- Cycle-2 ordering



GRID SIZE SELECTION

- Wells are generally considered in the center of cells
- Leave a few cells between wells(at least 2)
- Avoid large size variations between cells: ratio - 2
- Limit the number of cells:
  - Matrix size - f(number of cells)^2
  - Linear system solution - 30 - 50 % of CPU time
  - Time step decreases with cells size (stability criteria)

- Grid system must be carefully selected at beginning of study

ACTIVE and DEAD CELLS

- **Dead Cells**
  - Their porous volume is 0
  - Off-reservoir cells,

    allowing to represent a reservoir with an arbitraary form within a Cartesian geometry (parallelepiped).

  - => $Vp = (\Delta x \cdot \Delta y \cdot \Delta z \cdot ø \cdot Hu/Ht) \cdot MULPV$

- **Active Cells**
  - Their porous volume is > 0

➡ Desactive cells with low Vp (<MinPoreV)

GEOLOGICAL CONSTRAINTS

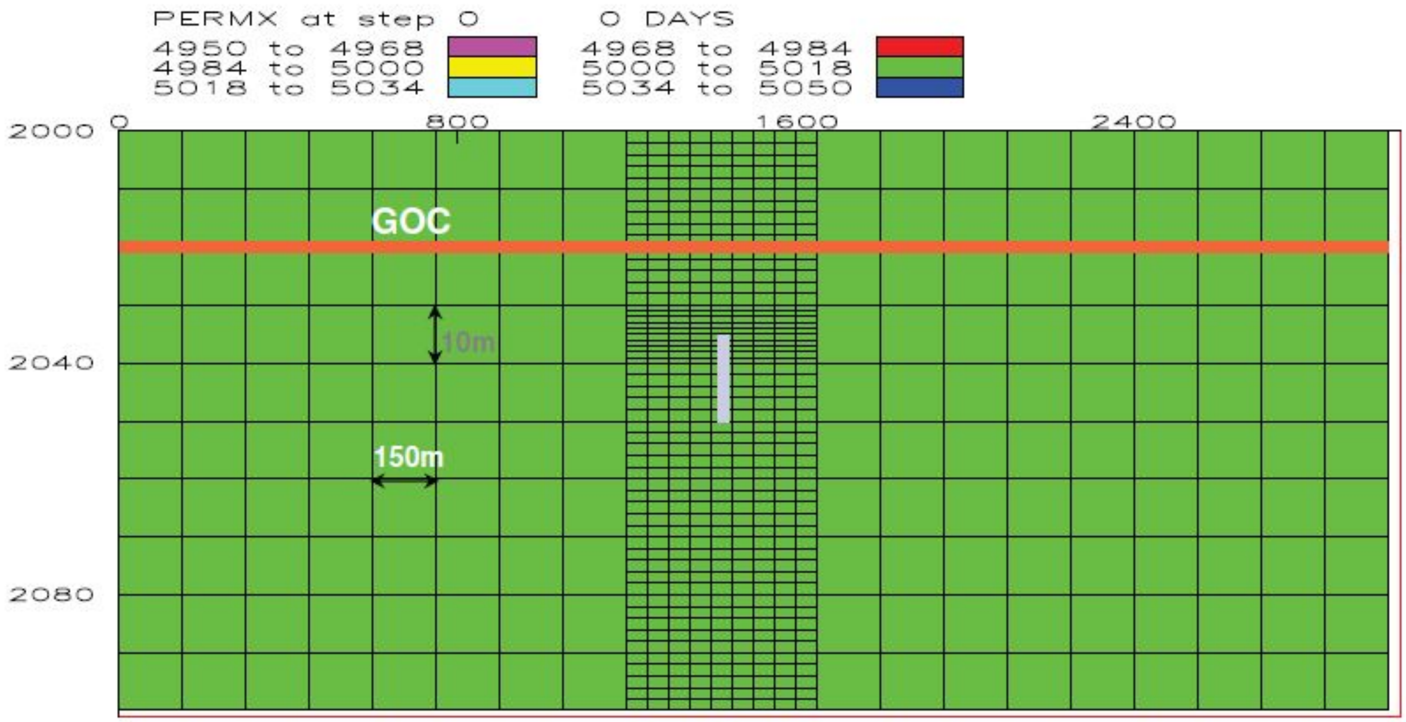
- The grid orientation should be parallel to:
  - the major faults direction, so that the grid block limits follow the fault trace. It produces a better representation of the transmissivity reductions if faults are present, with partial or total sealing effect.
  - the fracture direction, in order to represent the permeability anisotropy *kx* vs *ky*.
  - The direction of sediment supply, for a better representation of drain, or to align with the main axis of turbiditic supply.

CHOICE OF VERTICAL DISCRETIZATION

- Geological constraints: Good representation of the limits (layers, units), the barriers and the drains
- Dynamic constraints: Good representation of the displacement mechanisms:
  - Fingering, gas tongue
  - Gravity drainage effect (segregation, gas injection)
  - Oil rim
- Numerical constraints: fine discretization around wells:
  - Good representation of well completions
  - Coning
  - Horizontal well

➡ Alternative solution: **LGR** (Local Grid Refinement)

Using LGR to model gas coning

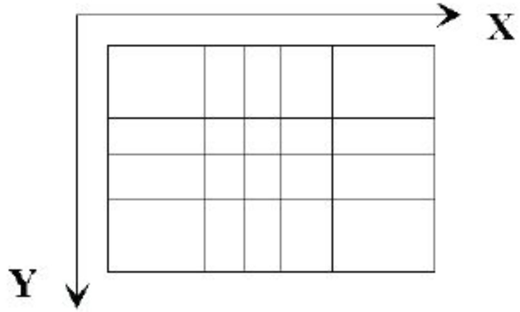


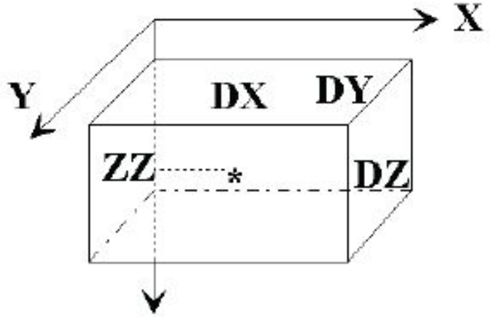
Kx=Ky=Kz=5000 mD

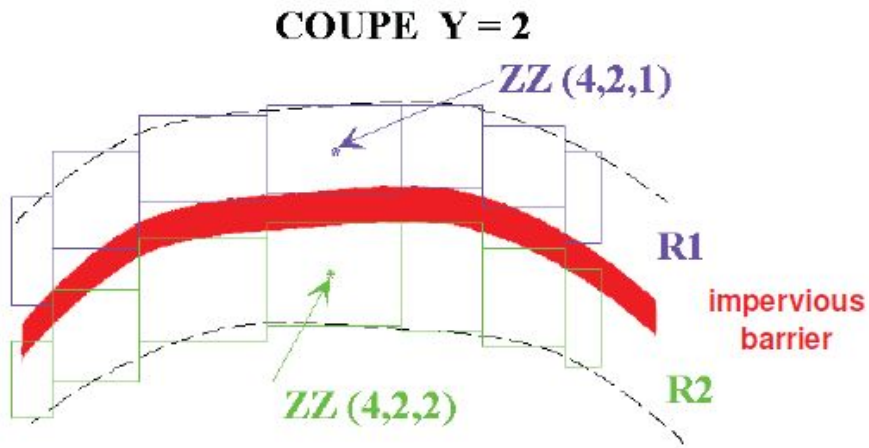
Qo = 6000 m3/j

Block-centered grid

- Collection of parallelepipeds defined by discrete steps and location of the cell center







Block-centered grid

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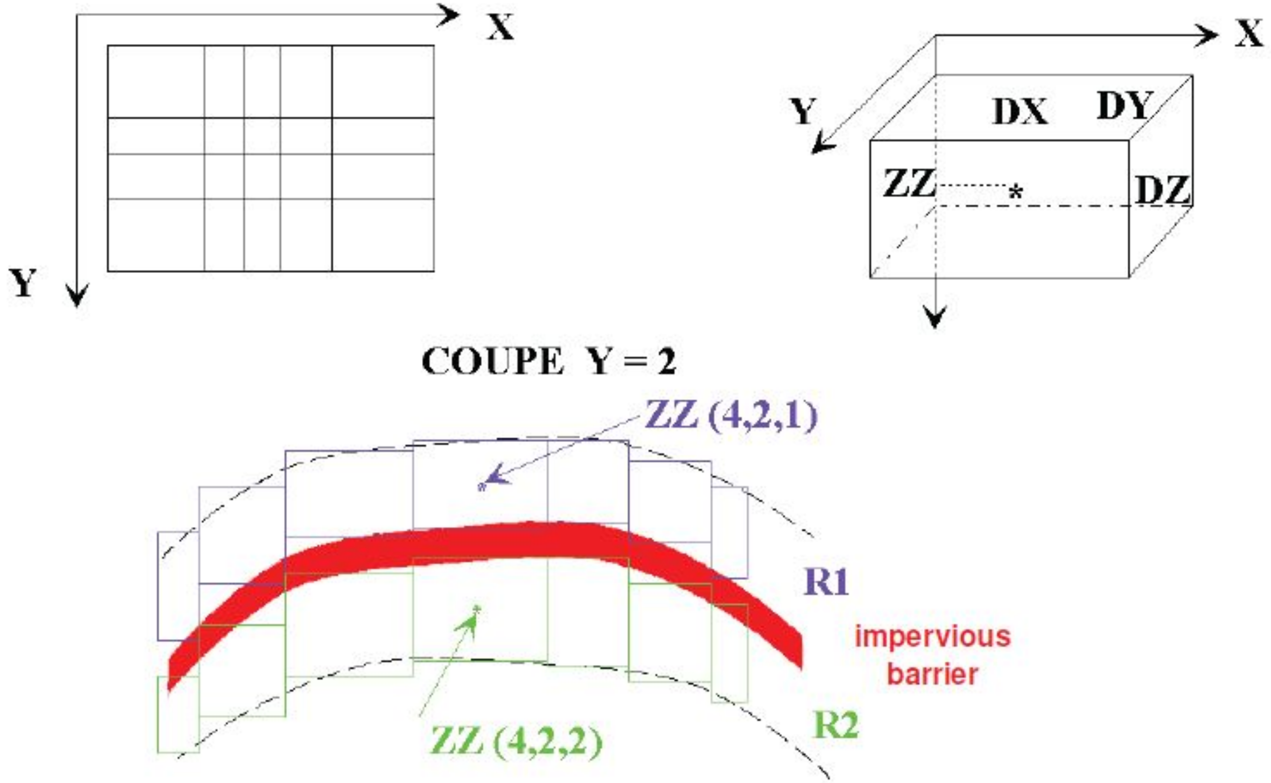
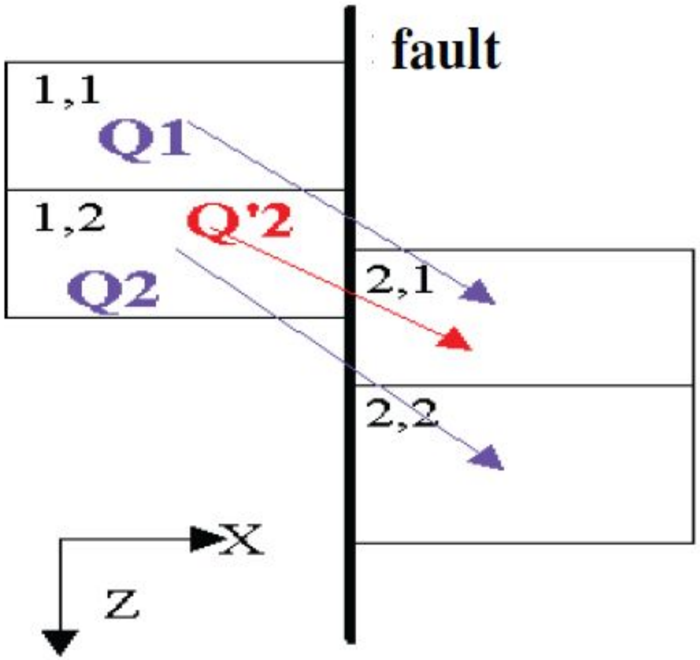


Block-centered grid



between numerically neighboring cells

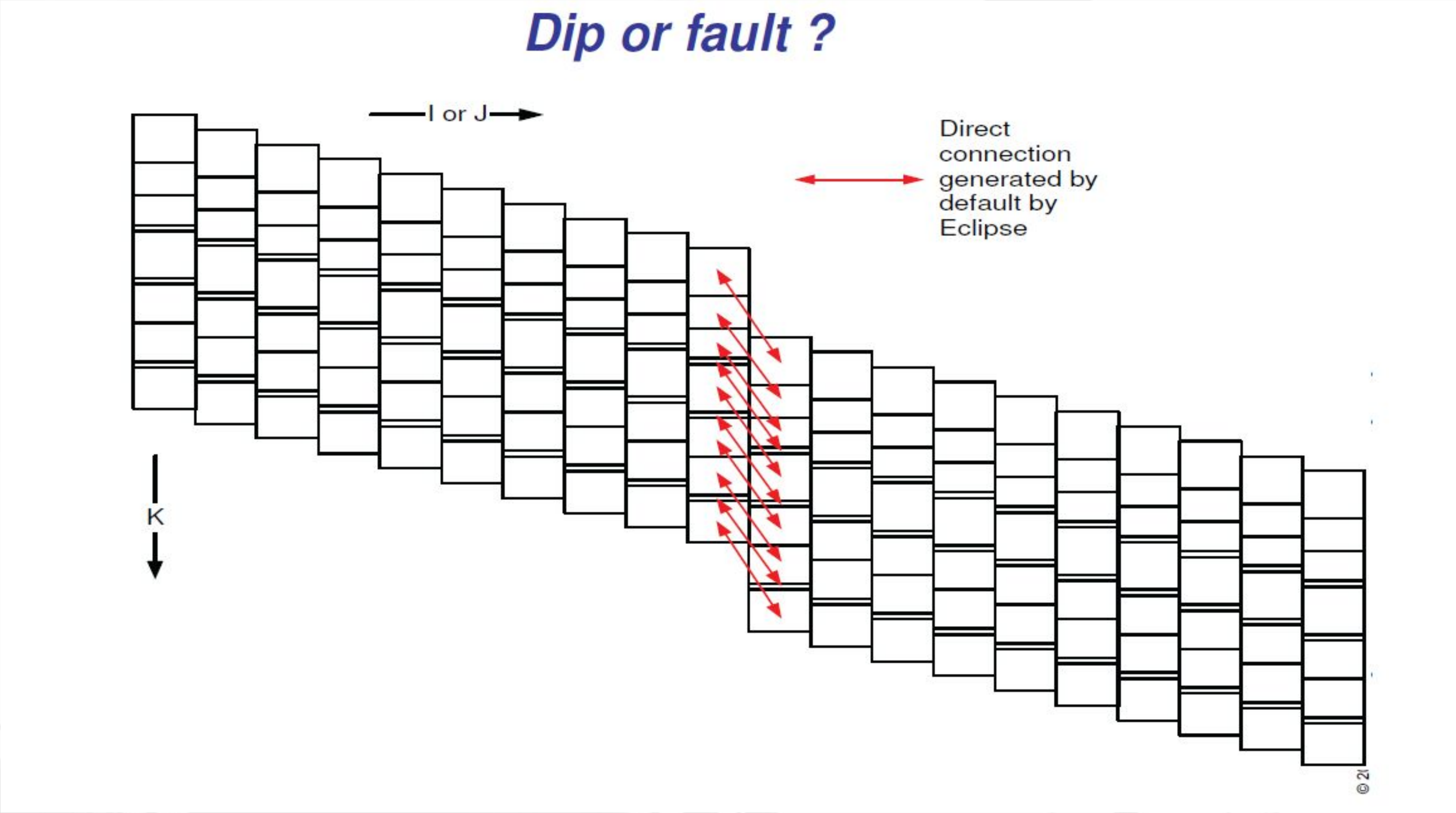
➔ physical flow not always respected

$$Q_1 = \frac{T_{1,1}}{\mu}(P_{2,1} - P_{1,1})$$

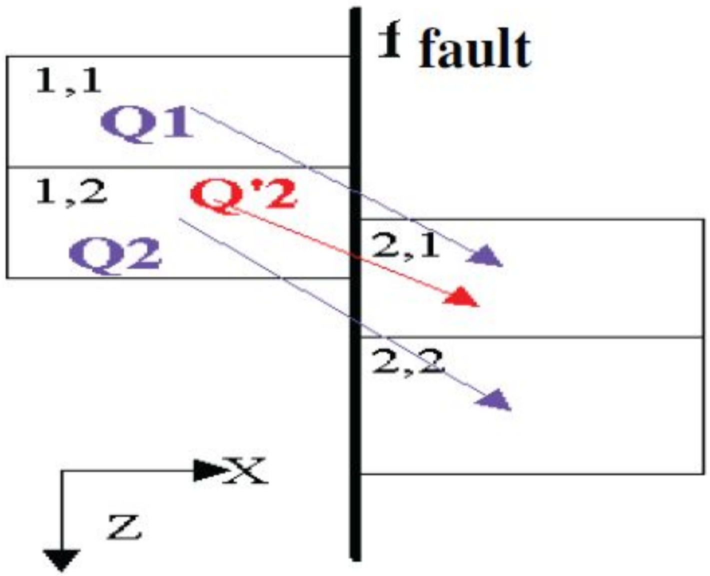
$$Q_2 = \frac{T_{1,2}}{\mu}(P_{2,2} - P_{1,2})$$

$$Q'_2 = 0$$

Dip or fault ?


Dip or fault ?
I or J
K
Direct connection generated by default by Eclipse

CPG grid intercell flow

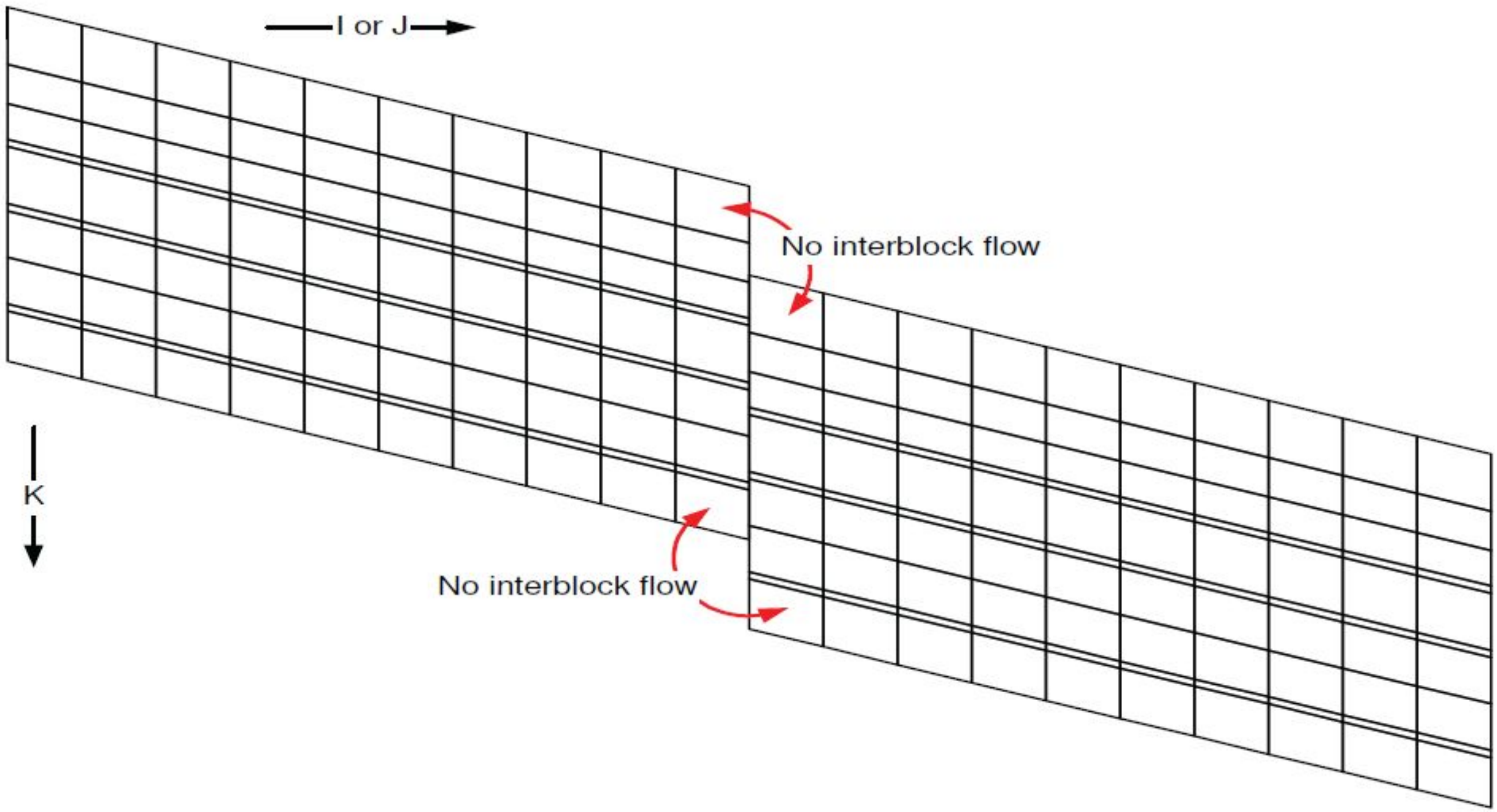


$$Q_1 = 0$$

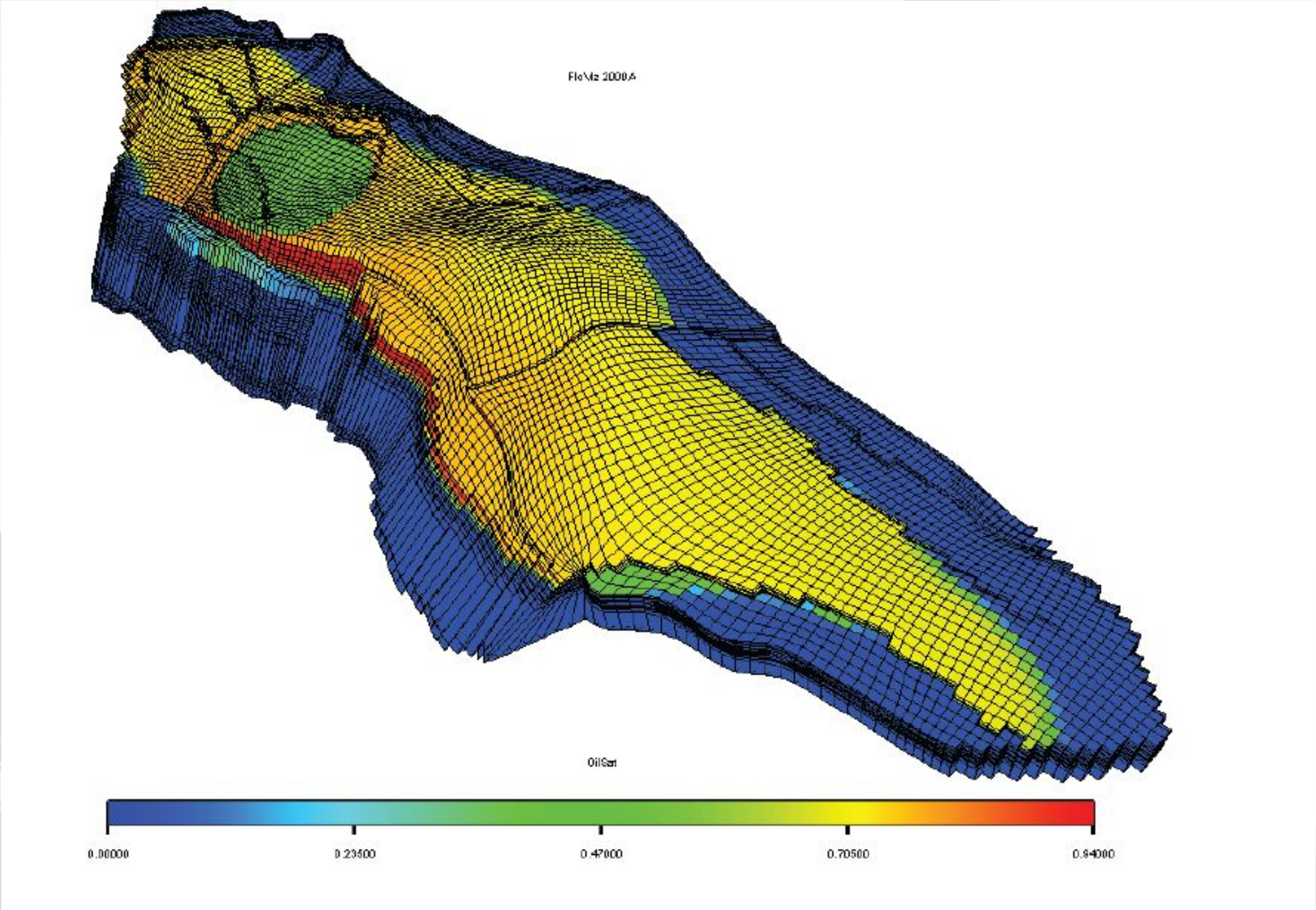
$$Q_2 = 0$$

$$Q'_2 = \frac{T'_{1,2}}{\mu}(P_{2,1} - P_{1,2})$$

Fault description in CPG grid



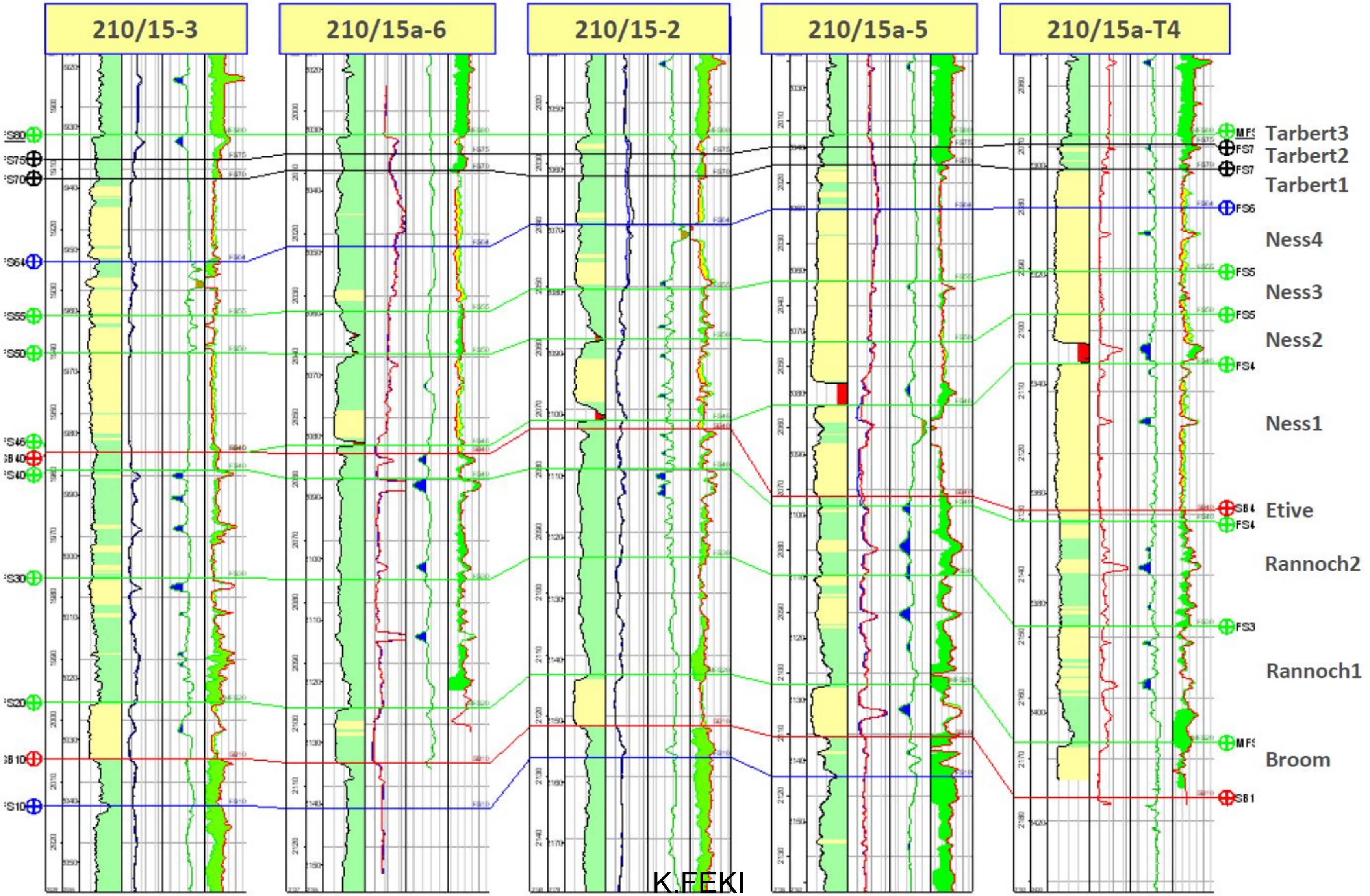
Example of CPG reservoir model



Fault description in CPG grid

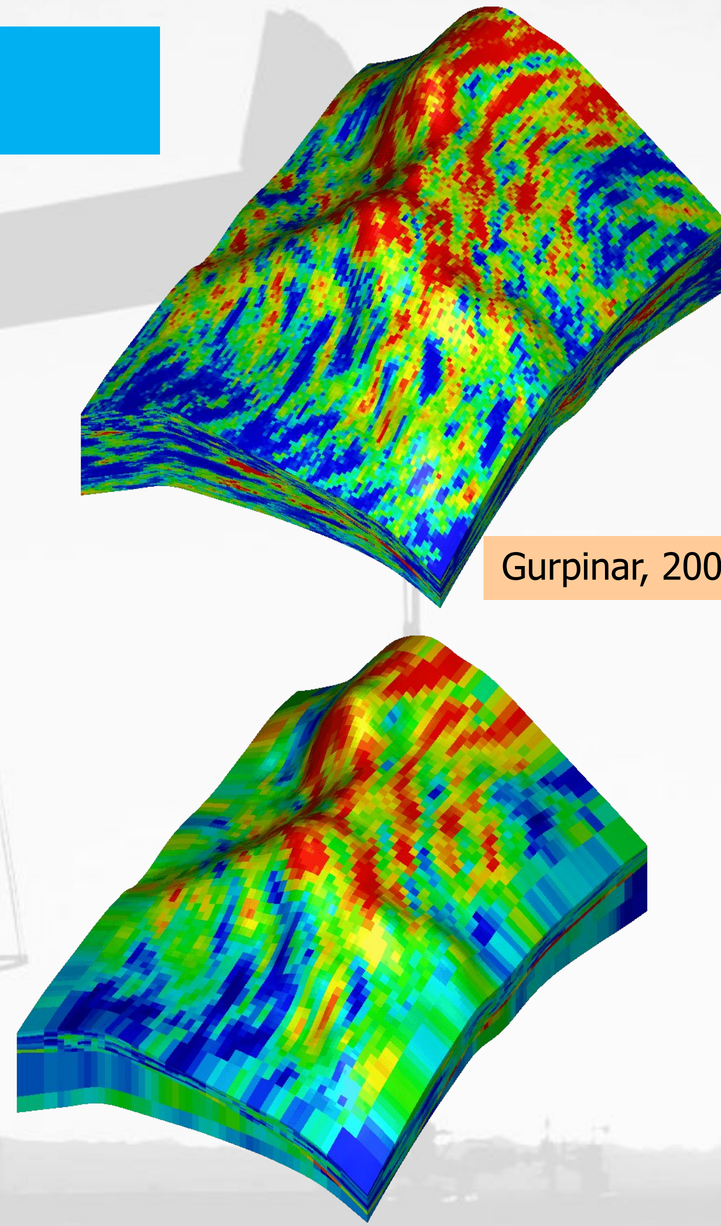
- **Reservoir layering**
  - identification of log correlations
  - Identification of flow units
- **Population of the petrophysical model**
  - Definition of Net to Gross, Porosity and Permeability per cell
  - Two main problems
    - Interpolate (or extrapolate) data in non recognised areas.
    - Give an average for each parameter in each grid cell.
- **Upscaling**
  - Reservoir engineering data are not constant in one grid cell.
  - Hence the necessity for each parameter to precise:
    - the parameter distribution in one the grid cell.
    - How to replace this distribution by one average value.

Reservoir layering: Use of log Correlation



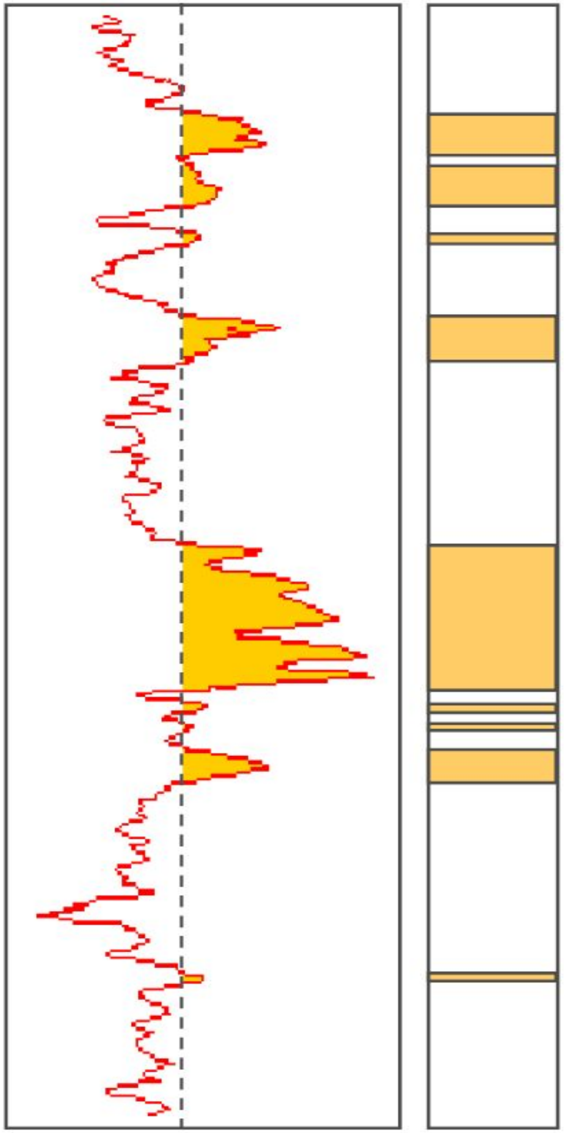
Upscaling

- Optimum level of and techniques for upscaling to minimize errors



Gurpinar, 2001

Rock properties: Main parameters



Non reservoir

Reservoir

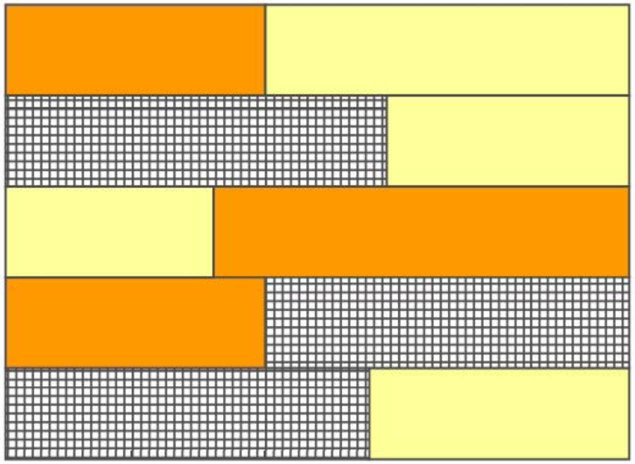
$$NTG = \frac{\text{Net thickness}}{\text{Gross thickness}}$$

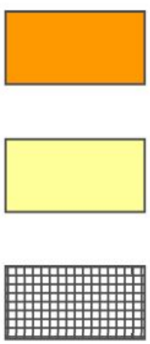
Porosity

Permeability

Fluid Saturation

Rock properties: Net thickness and porosity





Facies 1 ($\Phi1$, Vu1)

Facies 2 ($\Phi2$, Vu2)

Non reservoir

Cell Volume : $Vt = \Delta x \,.\, \Delta y \,.\, \Delta z$

Net Volume : $Vu = Vu1 + Vu2$

Porous Volume : $Vp = \Phi 1 \,.\, Vu1 + \Phi 2 \,.\, Vu2$

Net Thickness : $Hu = Ht \,.\, Vu / Vt$

Porosity : $\Phi = Vp / Vu$

Rock properties: Compressibility

Pores : $$Cp = \frac{1}{Vp}\frac{dVp}{dP}$$

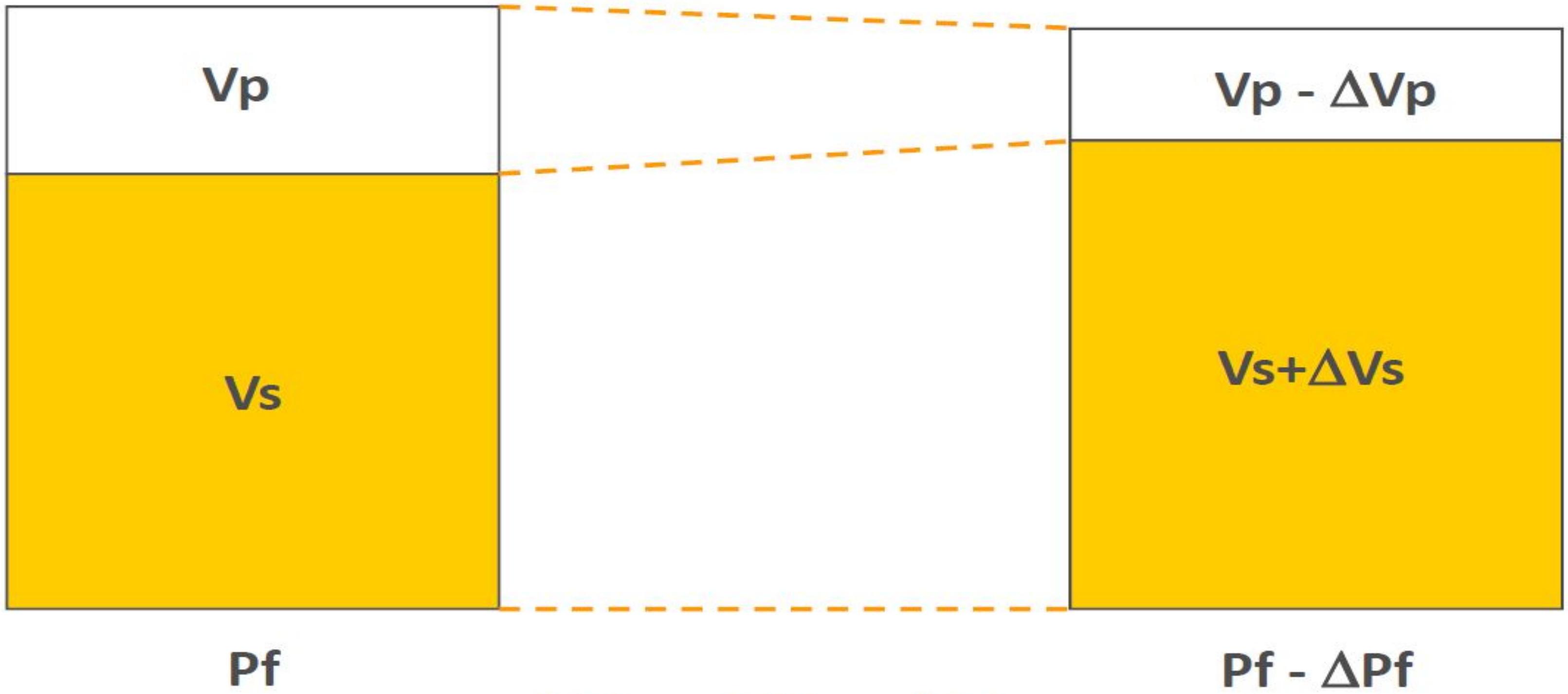
Solid : $$Cs = -\frac{1}{Vs}\frac{dVs}{dP}$$

Total : $$Ct = \frac{1}{Vt}\frac{dVt}{dP}$$

Pore compressibility and total compressibility are not identical :

$$Ct = \Phi \,.\, Cp - (1 - \Phi) \,.\, Cs$$

Rock properties: Compressibility

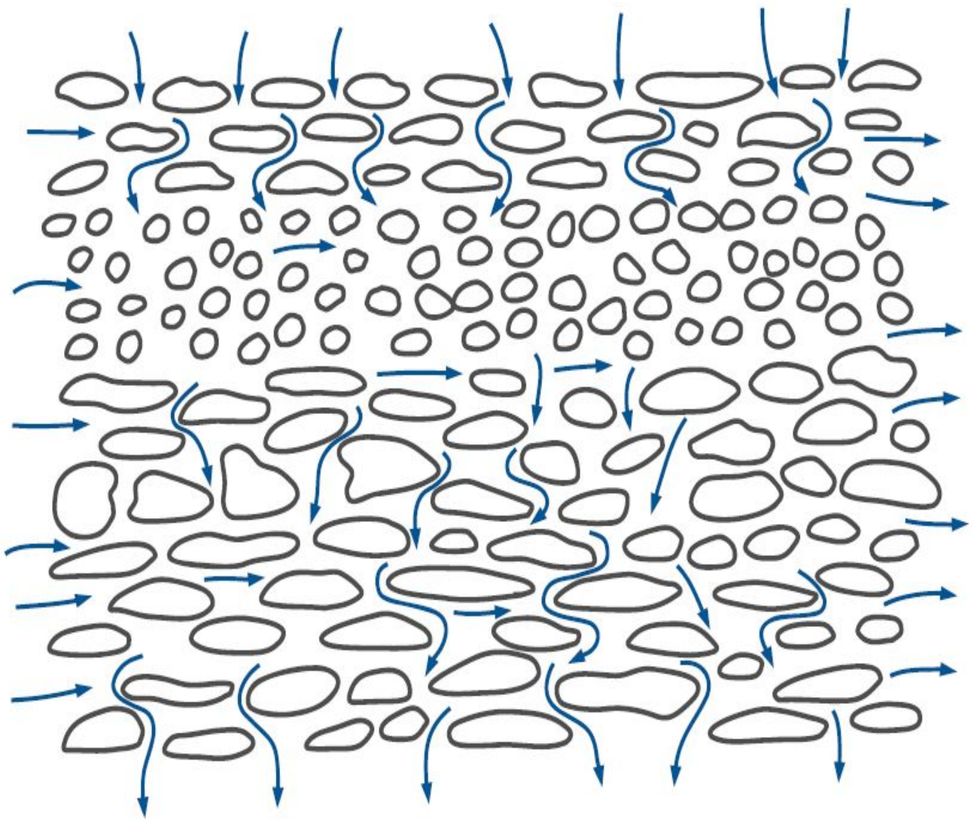


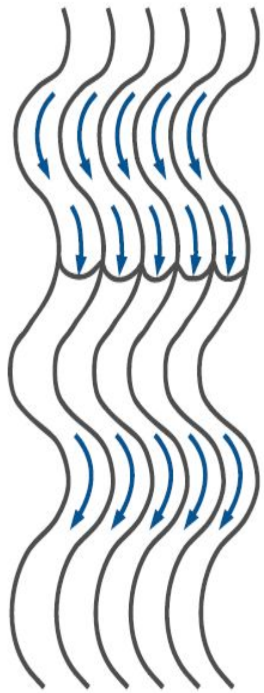
$$\Delta Vt = \Delta\, Vp - \Delta Vs$$

$$Vt\, Ct = Vp\, Cp + Vs\, Cs$$

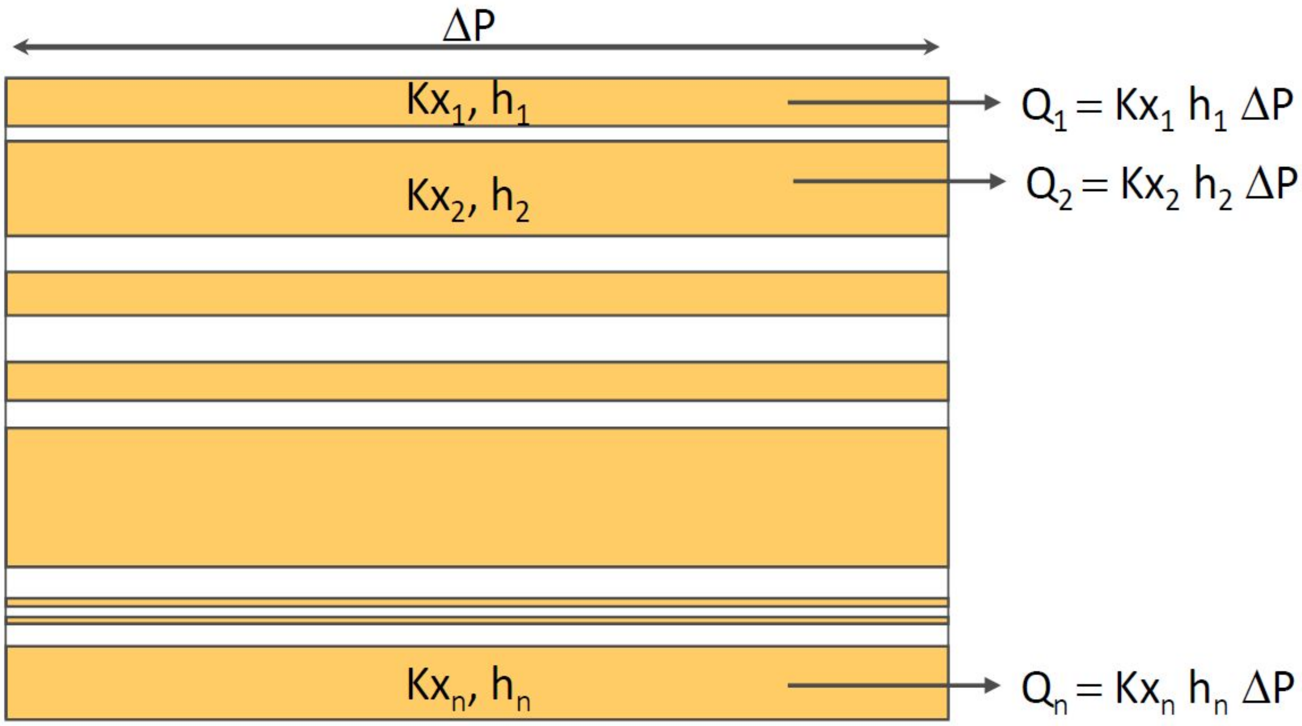
$$Ct = \frac{Vp}{Vt} Cp + \frac{Vs}{Vt} Cs$$

Horizontal & Vertical Permeability





Horizontal Permeability



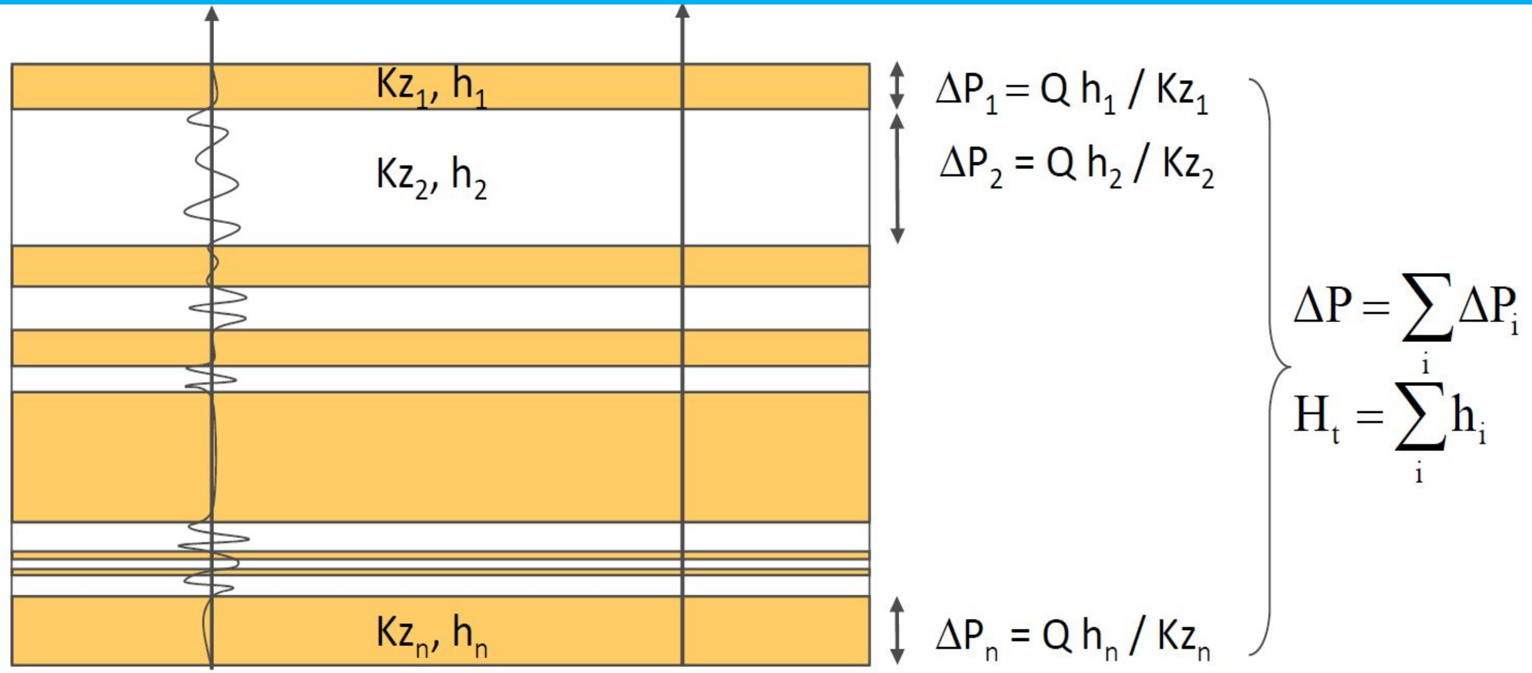
$$Q = \sum_i Q_i$$

$$H_u = \sum_i h_i$$

$$NTG = H_u / H_t$$

$$Kx\, H_u = \frac{Q}{\Delta P} = \frac{\sum_i Q_i}{\Delta P} = \sum_i Kx_i\, h_i$$

Vertical Permeability



$$\frac{H_t}{Kz} = \frac{\Delta P}{Q} = \frac{\sum_i \Delta P_i}{Q} = \sum_i \frac{h_i}{Kz_i}$$

History Matching

In general two phases are distinguished :

- **Initialisation**
  - model data checking
  - calculation of fluids in place
- **History match**
  - run with imposed rate
  - calculation of P, Fw, GOR
  - comparison with field measurements
  - adjustment of parameters
  - modification of input data
  - New run

History Matching

Objective:

- reproduce with the model the measured evolutions of pressure,BSW and GOR by well ,by zone or for the entire field

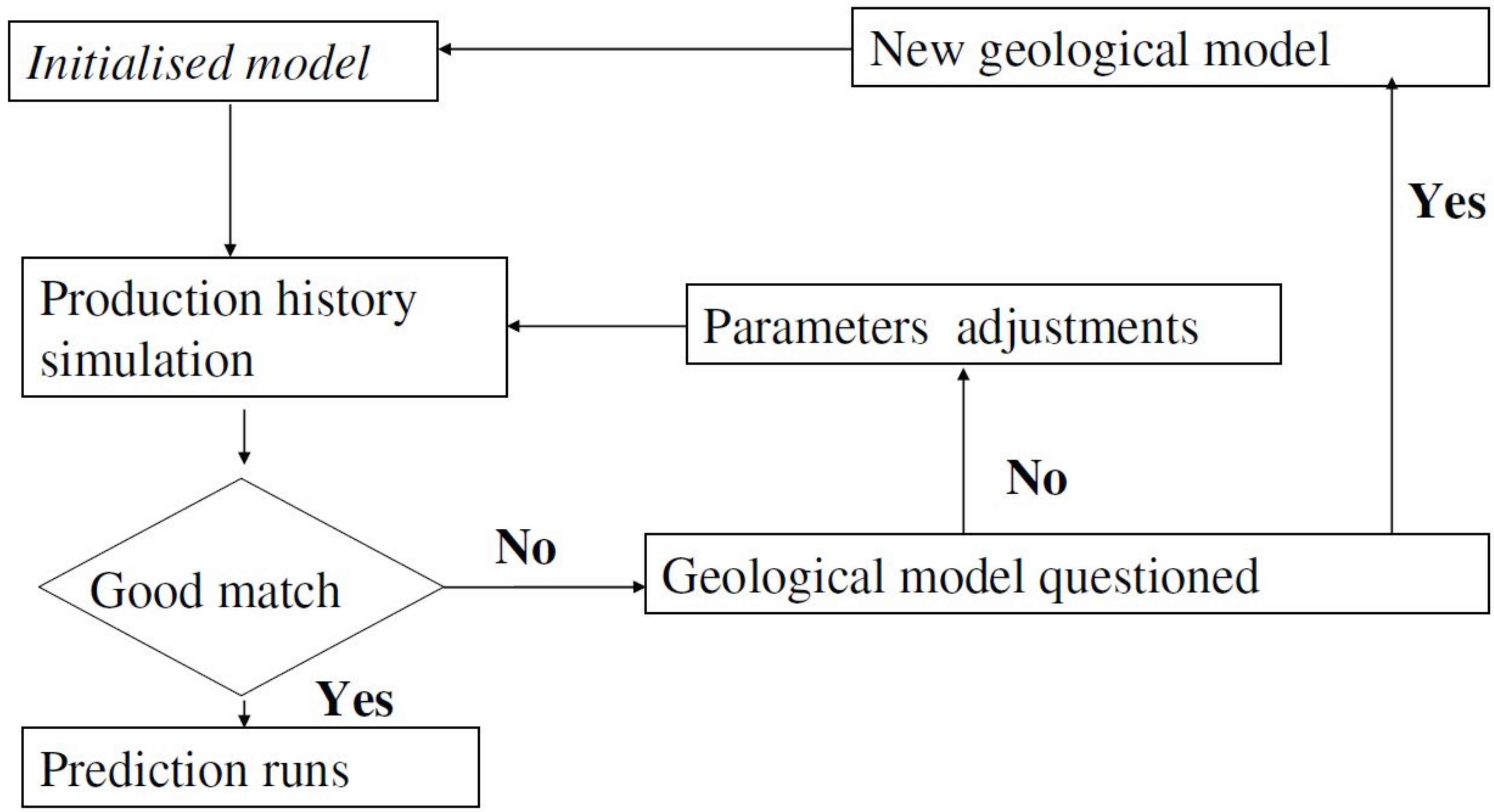
Difficulties:

- uncertainties on fault and flow barriers network ;parameters are dependent

Rule of thumb:

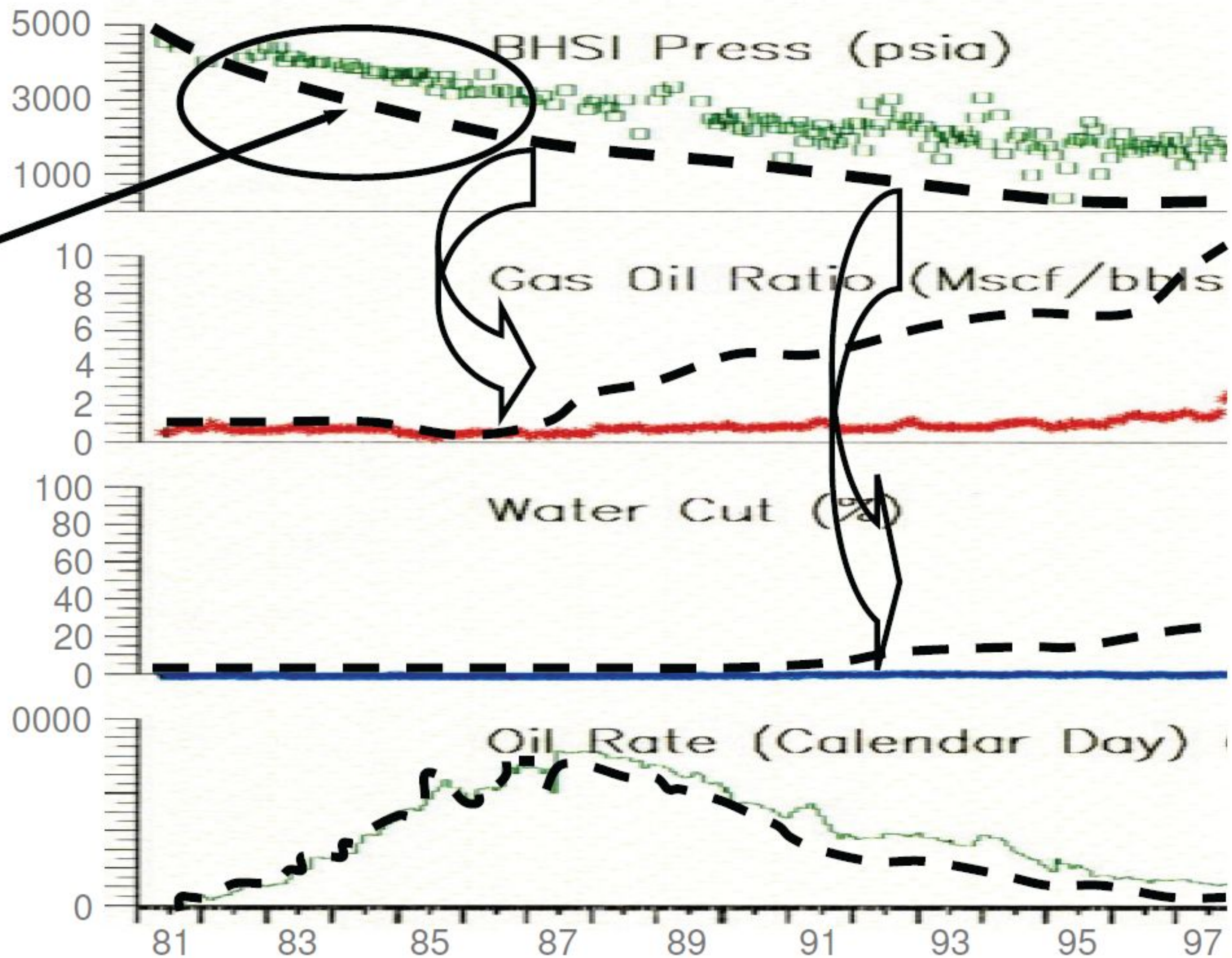
- predictions are reliable on a period twice the production period

History Matching

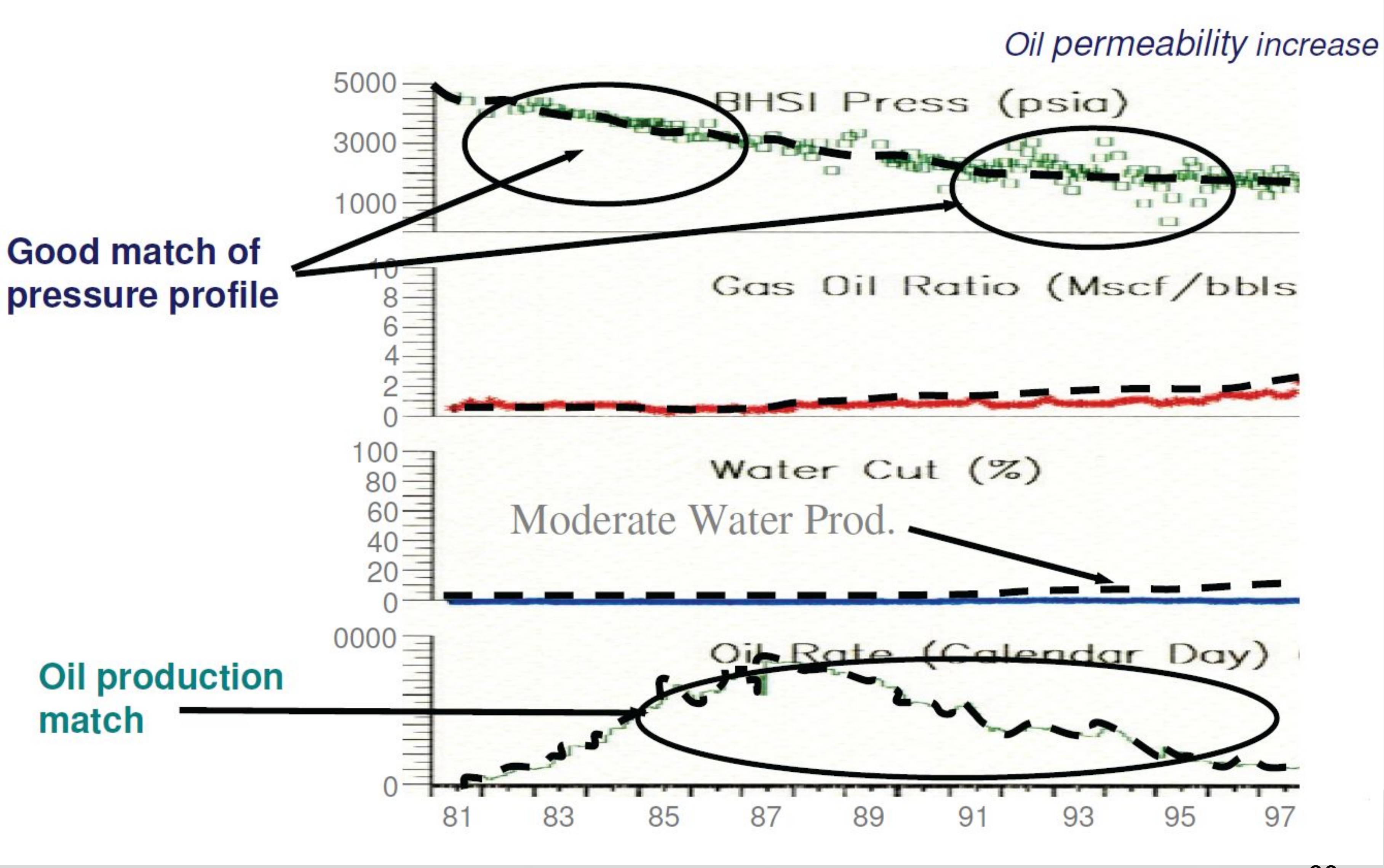


FIRST STEP - GENERAL FIELD MATCH - RUN 1

Wrong initial
Pressure drop



FINAL STEP - GENERAL FIELD MATCH - RUN 3



Predictions

- Predictions can be run once history match has been completed. The objective is to predict the future performance of the reservoir under different exploitation scenarios.

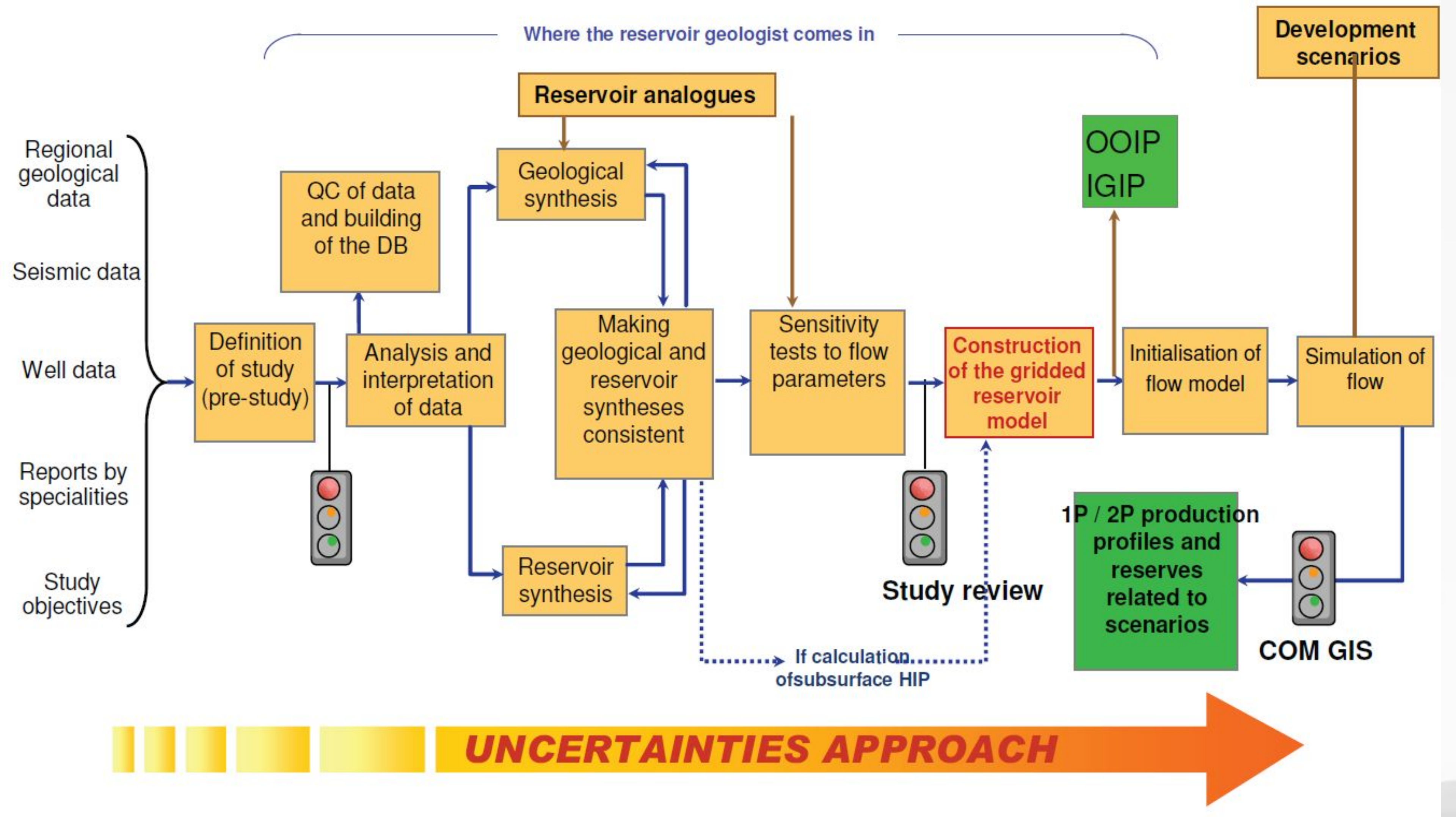
- Results of major interest are:
  - → future oil performance
  - → future water-cut and GOR evolution
  - → pressure evolution
  - → fluid contact evolution
  - → work-over requirements
  - → drilling requirements
  - → surface facilities requirements
  - → estimate the recovery factor

- The analysis of results must be done by comparison of the different cases.

Predictions

- **Give always a clear and concise report with:**
  - statement of the objectives of the study
  - description of the model
  - presentation of the results
  - conclusions and recommendations
- **In most of reservoir studies give both :**
  - managerial report (read by many people)
  - detailed report (read by only a few people, but essential for future update)
- **Don't forget to save data, results and reports on magnetic support (tape) or CDRom.**

Predictions



Fluid flow equations

- Conservation laws
  - Conservation in mass

    Assume:
    - Isothermal condition
    - complete and instantaneous phase equilibration in each cell
  - Conservation in energy
  - Conservation in momentum
- Additional constraints
- Wells and facilities
- Large number of non-linear equations

Fluid flow equations

- Type of fluid in the reservoir
- Flow regimes
- Reservoir geometry
- Number of flowing fluids in the reservoir

Type of fluid in the reservoir

- Incompressible
- Slightly compressible
- Compressible

Flow regimes

- Steady State flow
- Unsteady State flow
- Pseudo Steady State flow

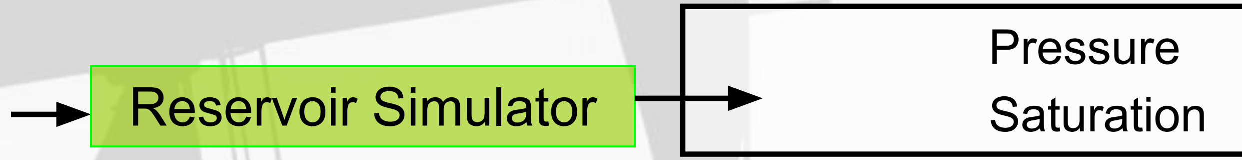
Reservoir geometry

- Radial flow
- Linear flow
- Spherical and Hemispherical flow

Number of flowing fluids in the reservoir

- Single Phase flow
- Two phase flow
- Three phase flow

IN OUT



Newton-Raphson (IMPLICIT)

all primary variables are calculated at the same time.

IMplicit Pressure Explicit Saturation (IMPES)

The IMPES procedure solves for pressure at the new time level using saturations at the old time level, and then uses the pressures at the new time level to explicitly calculate saturations at the new time level

Numerical Models

- Black oil model
  - Depletion
  - Water Injection
  - Component: oil water gas
  - Phase: Oil water gas

Compositional model

- Gas injection to increase or maintain reservoir pressure
- Miscible flooding as the injection gas goes into solution with oil
- Carbon dioxide flooding, with the gas soluble in both oil and water
- Thick reservoirs with a compositional gradient caused by gravity
- Reservoirs with fluid compositions near the bubblepoint
- High-pressure, high temperature reservoirs
- Natural-fracture reservoir modeling.
    - Component: C1,C2, ….So2,H2S,N2,..
    - Phase: Oil water gas

Chemical model

- Polymer and surfactant injection
  - Component: Water oil surfactant alcohol
  - Phase: Agues oleic microemulsion

Reservoir simulators

- ECLIPSE
- GPRS
- SENSOR
- NEXUS
- UTCHEM
- Boast 3
- COMET3
- …

- ✔ Objective
- ✔ Accuracy
- ✔ Time
- ✔ Limitations
- ✔ User friendly
- ✔ Easy to integrate
- ✔ …

Eclipse reservoir simulator

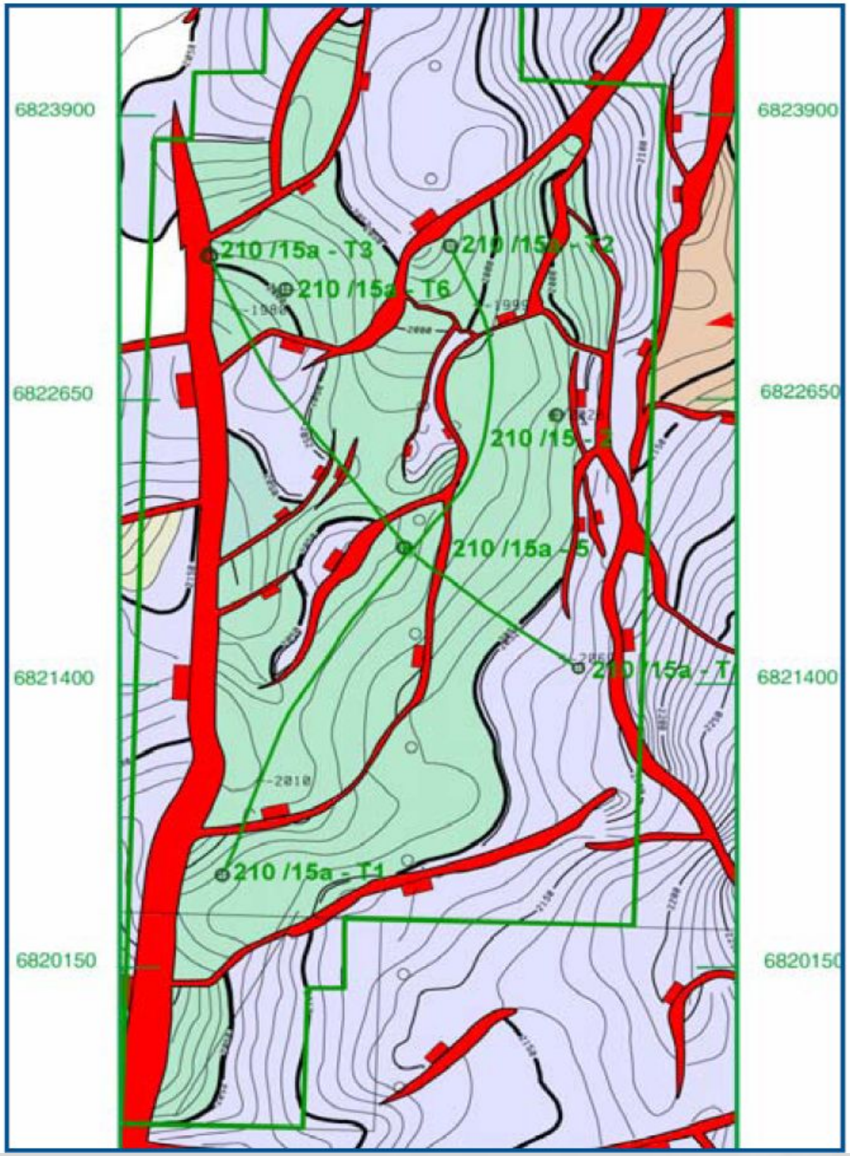
- Commercial reservoir simulator for over 25 years

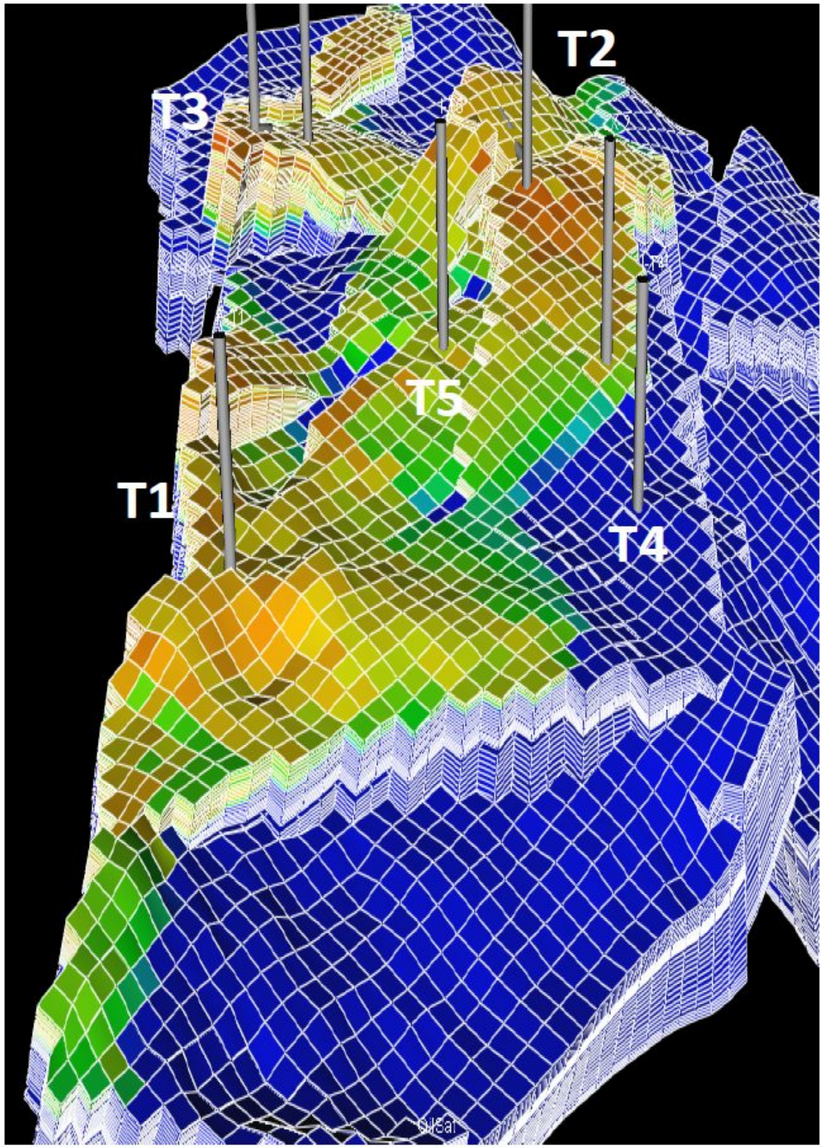
- **Black-oil**
- **Compositional**
- **Thermal**
- **Streamline**

Eclipse reservoir simulator

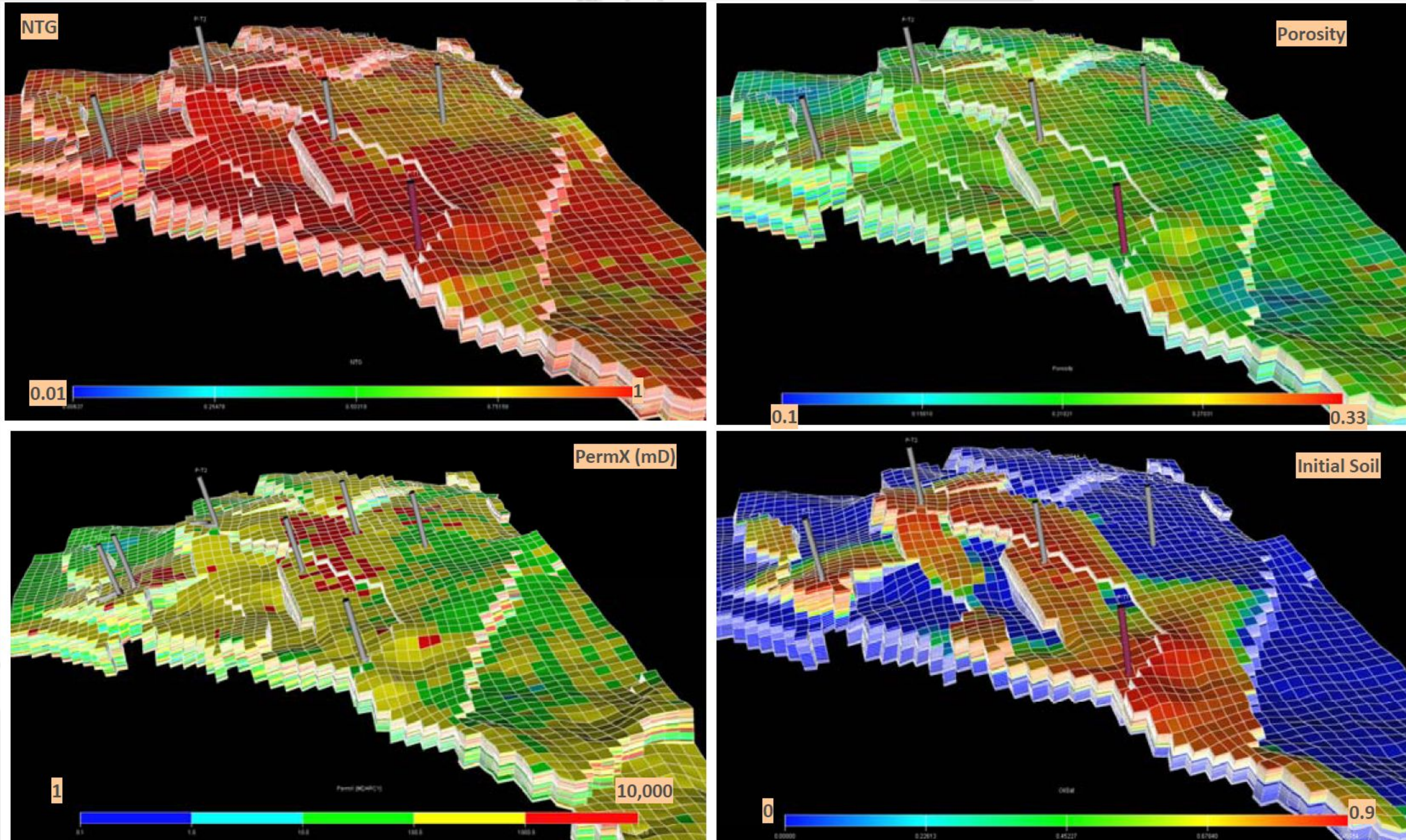
- ✔ Local Grid Refinement
- ✔ Gas Lift Optimization
- ✔ Gas Field Operations
- ✔ Gas Calorific Value-Based Control
- ✔ Geomechanics
- ✔ Coalbed Methane
- ✔ Networks
- ✔ Reservoir Coupling
- ✔ Flux Boundary
- ✔ Environmental Traces
- ✔ Open-ECLIPSE Developer's Kit
- ✔Pseudo-Compositional
- ✔EOR Foam
- ✔EOR Polymer
- ✔EOR Solvent
- ✔EOR Surfactant
- ✔Wellbore Friction
- ✔Multisegmented Wells
- ✔Unencoded Gradients
- ✔Parallel ECLIPSE

Grid definition : Example





Rock properties: Main parameters



Thank You!

Quiz

- Look at the following sentences . Establish for each one if it is a true or false

1. Reservoir layering should be defined before XY grid
2. Reservoir layering is derived from well data
3. Reservoir layering is derived from fault geometry
4. Reservoir layering should respect wells correlation
5. Reservoir layering should respect flow unit
6. Grid geometry can vary with time
7. Any grid has locally three main flow directions
8. Grid axes should be locally orthoganal
9. One cell can communicate with maximum of 6 neighbours
10. grid blocks are refered by three indexes (I ,j , k)

Reservoir layering: Quiz

- **Look at the following sentences. Establish for each one if it is true or false.**
  - 1. Reservoir layering should be defined before XY grid.
  - 2. Reservoir layering is derived from well data.
  - 3. Reservoir layering is derived from fault geometry.
  - 4. Reservoir layering should respect wells' correlation.
  - 5. Reservoir layering should respect flow units.
  - 6. Reservoir layering should respect facies distribution.
  - 7. Reservoir layering should respect initial pressure distribution.
  - 8. Reservoir layering should respect pressure evolution with time.
  - 9. Reservoir layering should respect maximum flooding surfaces
  - 10. There are specific porosity permeability relationships per layer.

Grid definition: Quiz

- **Look at the following sentences. Establish for each one if it is true or false.**

  - 1. Grid geometry can vary with time.
  - 2. Any grid has locally three main flow directions.
  - 3. Grid axis should be locally orthogonal.
  - 4. CPG geometry depends on pillars definition.
  - 5. Each CPG cell is defined by six corners.
  - 6. CPG geometry can deliver variable axis orientation.
  - 7. One cell can communicate with a maximum of 6 neighbours.
  - 8. Grid blocks are referred by three indexes (I, J, K)
  - 9. Grid blocks (I,J,K) and (I+1, J+1, K+1) are neighbours
  - 10. Any locally orthogonal grid is suitable for one given reservoir