Australian Government

Geoscience Australia

CO_2 storage capacity and injectivity analysis through the integrated reservoir modelling

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Beijing, P. R. China

April 18th-20th 2012

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China Australia Geological Storage of CO_2

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Outline

1. Integrated Reservoir Modelling
2. Basin-Scale Modelling
3. Reservoir Characterisation and Static Modelling
4. Dynamic Reservoir Simulation
5. Remarks

1 Integrated Reservoir Modelling

- **Basin analysis and basin-scale modelling**
  - •Basin-scale assessment - Basin modelling

- **Reservoir characterisation and static modelling**
  - •Pool all the information related to reservoir together
  - •Geocellular or grid model - Static geological modelling
  - •Reservoir upscaling

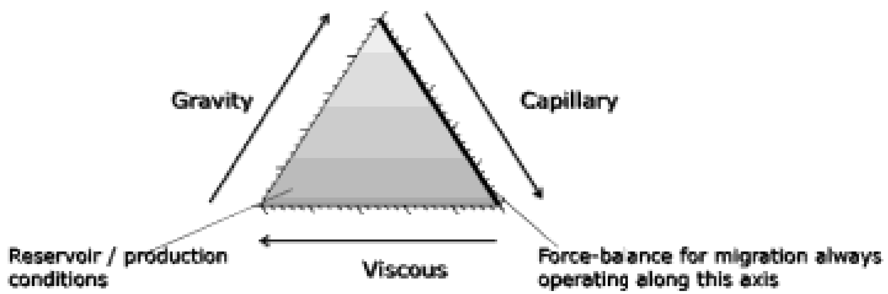
- **Dynamic simulation**
  - •Initial reservoir model: Rock and fluid properties
  - •Black-oil model
  - •Compositional simulation
  - •Coupled simulation with geochemical reaction/transport, geomechanical modelling and thermal capability
  - •etc.

2 Basin-Scale Modelling

- **<u>Basin analysis</u>**
  - Regional geology: Structure, seismic survey, stratigraphy,……
  - Pre-competitive study: Theoretical carbon storage potential

- **<u>Basin-scale modelling</u>** (Permedia, 2011)
  - Petroleum migration is controlled by capillary (resistive) and buoyancy (driving) forces
  - Flow rates are so low that viscous effects can be ignored
  - **<u>Modified invasion percolation techniques</u>** can be used to model these conditions but still honour the controlling physics
  - Basin modelling software (eg. Permedia): Model capillary-dominated petroleum transport (CO2Toolkit)

Migration forces

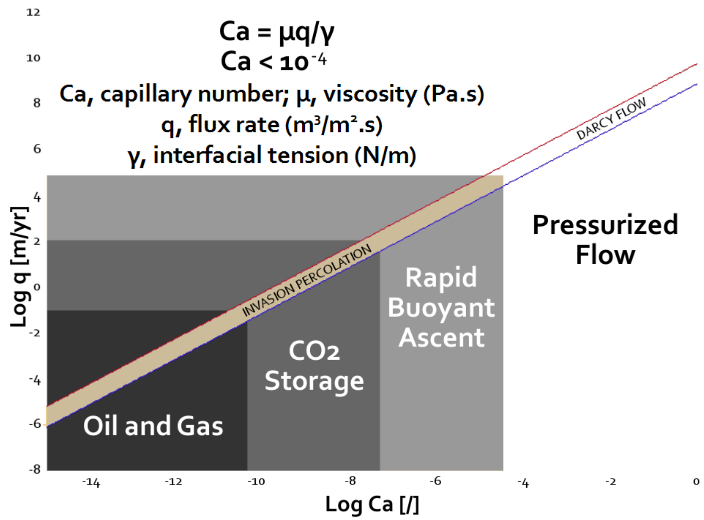


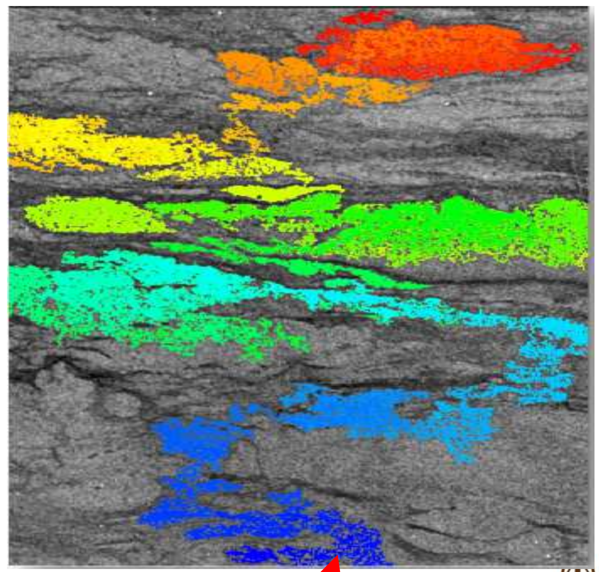
Basin-Scale Modelling

- Scaling theory for multi-phase flow domains. Hydrocarbons, CO_2 and even rapidly ascending buoyant fluids remain in the invasion percolation domain.

- The Darcy flow domain only occurs at high flow rates for pressurized flow.

- Migration pathway is determined by **<u>comparing the threshold capillary pressures in the neighboring cells</u>**.

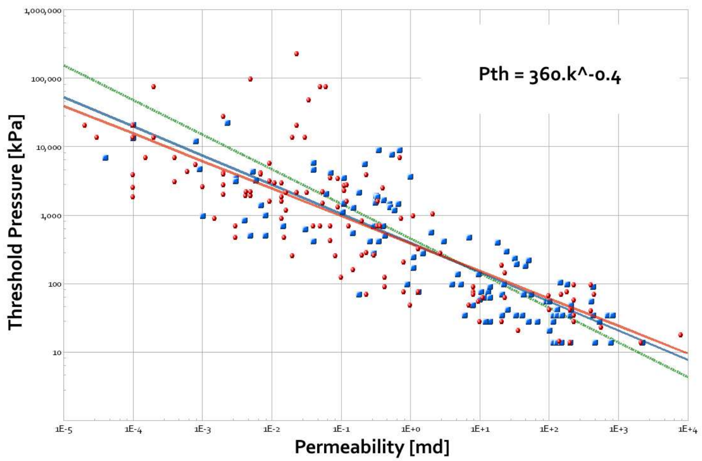




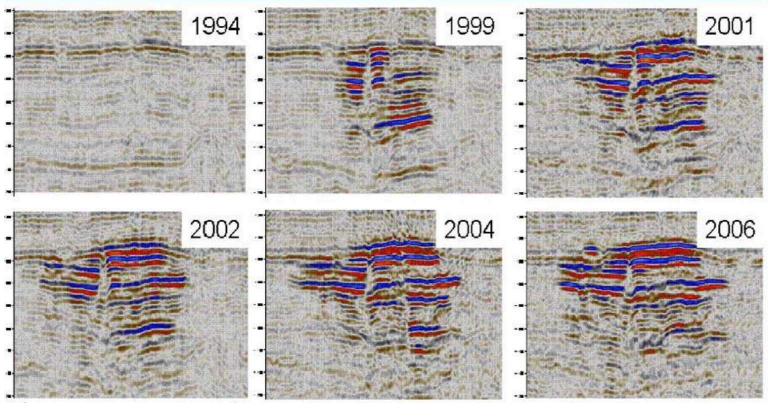
Source

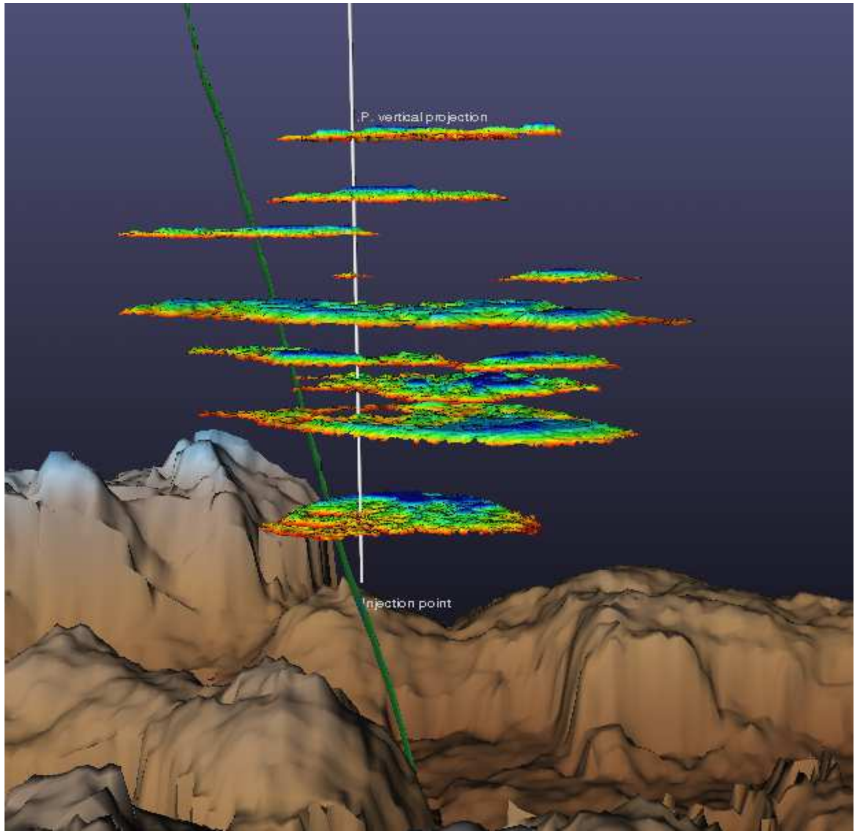
(Permedia, 2011)

Basin-Scale Modelling



✓Relationship between the threshold capillary pressure and reservoir permeability (after Sorkhabi and Tsuji, 2005)





✓Sleipner case study with Permedia (Cavanagh, 2009)

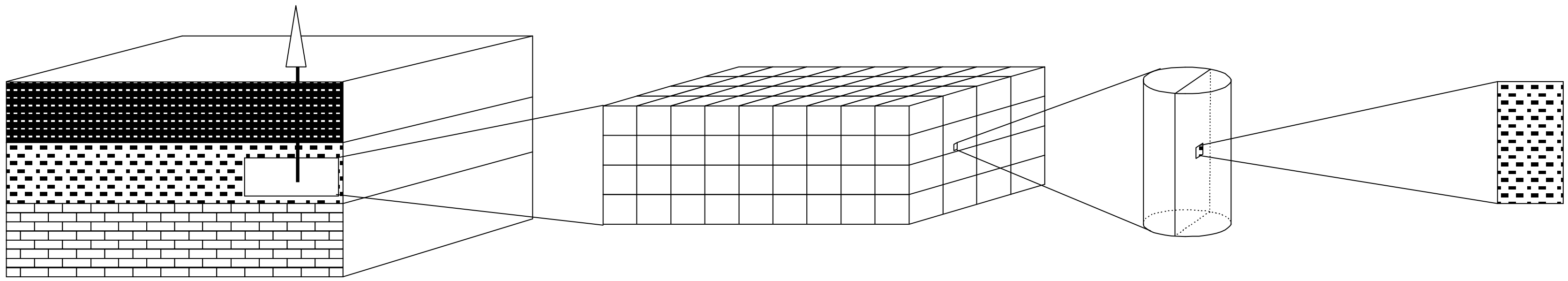
3 Reservoir Characterisation and Modelling

- **Objective:** *To assess the Characterized or effective CO_2 Storage Capacity*

  - ✓ Scales of reservoir data
  - ✓ General approach for characterisation
  - ✓ General issues in reservoir characterisation
  - ✓ Geological knowledge
  - ✓ Conceptual geological model
  - ✓ Numerical reservoir model and reservoir modelling
  - ✓ Upgridding and reservoir upscaling

Scales of Reservoir Data

Giga | Mega | Macro | Micro



Reservoir

Outcrop studies
Seismic surveys
Reservoir geometry
Sequence stratigraphy
Depositional modelling

Simulation

Tracer studies
Wireline logging
Pressure transients
Recovery efficiency
Reserves distribution

Core

Porosity
Permeability
Rel-perm curves
Capillary pressures
Residual saturations

Thin Section

SEM
Mineralogy
Pore throats
Cementation effects
Pore-size distribution

General Approach for Characterisation

- **Geophysics:** Data processing, structural interpretation, seismic attributes, seismic faciesmodelling, time-to-depth conversion.
- **Geology:** Structural geology, depositional environments/sedimentology, stratigraphy, reservoir geology/heterogeneity…
- **Core analysis:** Petrophysical properties, lithofacies, mineralogy/lithology.
- **Log analysis:** Log interpretation and correlation, eg., petrophysical properties, tops, contacts, flow units.
- **Inter-well interpolation:** Fine gridded models (pixel- or object-based).
- **Constraints:** Seismic attributes (2D/3D/4D), conceptual geological model, dynamic data (well test and production data).
- **Upscaling:** Coarse gridded models, averaging of petrophysical properties.

Reservoir Characterisation

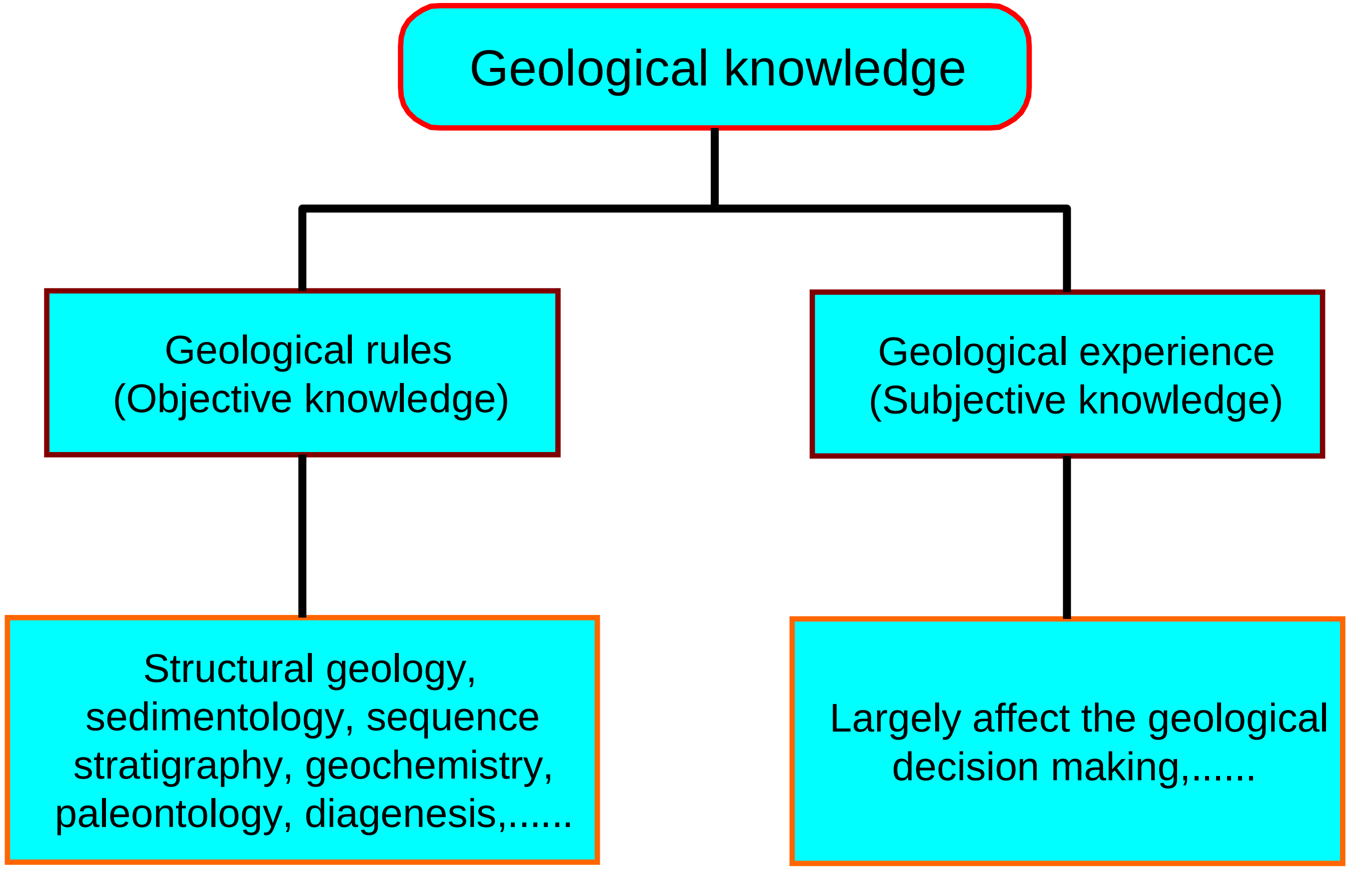
- Major problems:
  - ✓Reservoir heterogeneity
  - ✓Oversimplified reservoir description leads to poor recovery
  - ✓Inconsistencies of reservoir modelling practices
  - ✓Decision-making in reservoir management

- Applications:
  - ✓Hydrocarbon in place (OOIP, OGIP)
  - ✓Fluid flow simulation (reserves)
  - ✓Computer visualisation (high-speed graphics, virtual reality)
  - ✓Field development planning (well planning)
  - ✓Updating of reservoir model (a continuous process)

General Issues in Reservoir Characterisation

- Reservoir data are **limited**, **scattered**, **biased** and **noisy**.
- **Non-linear**, **multi-dimensional** data system.
- The major problem in earth sciences: **Getting the truth is impossible!**
- Reservoir modelling is an nonunique (open) problem.
- A good reservoir model must match all the observed data, but the reverse is never the case!
- Is the reservoir model **geologically interpretable**?
- What is known, unknown and unknowable? What is random?
- **Uncertainty** depends on **modelling scale**. Quantifying such an uncertainty is a problematic exercise.
- Model selection is:
  - ✓ data-dependent;
  - ✓ objective-dependent;
  - ✓ expert-dependent.

Geological Knowledge



Conceptual Geological Model

Conceptual modelling:

- Plays the central role for a long time!
- Models are highly non-linear and complex.
- Involves good understanding of physical and chemical processes in earth science.
- Depends heavily on the knowledge, judgement and intuition of the geologist(s).

Limitations of conceptual modelling:

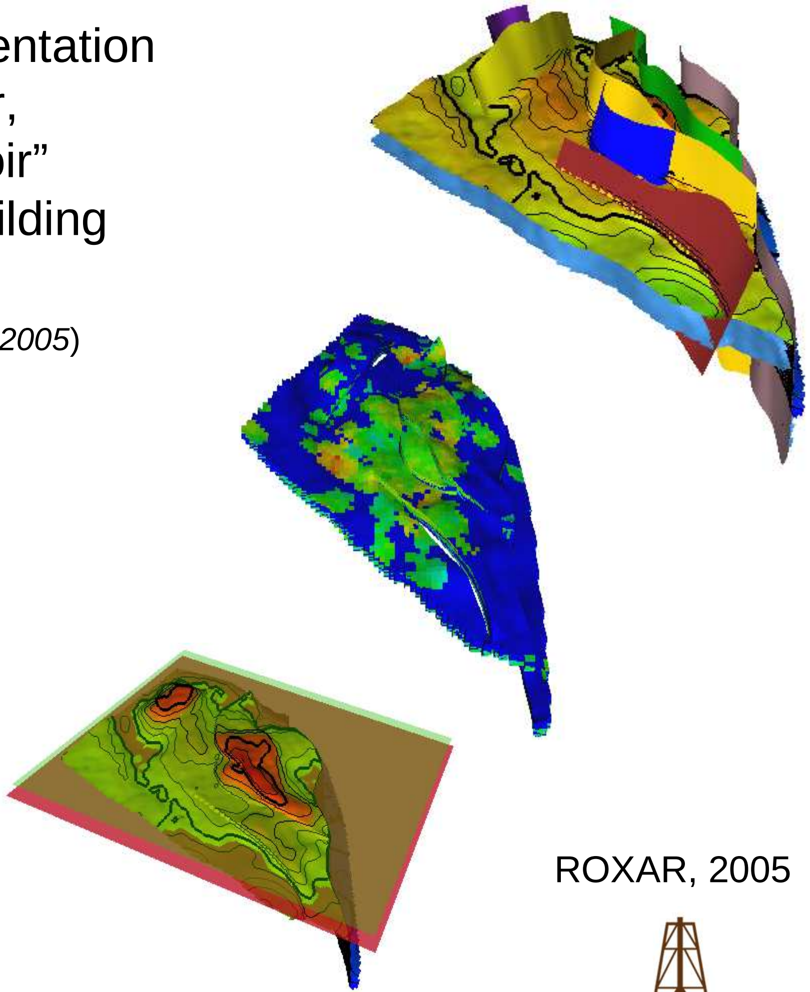
- Conceptual model is mostly of a symbolic nature (e. g. facies distribution, fracture) rather than a numerical one.
- Represents only the global trends of heterogeneities.
- Unable to produce fine scale distribution of properties in 3D.
- Interpretation is deterministic and subjective!

Numerical Reservoir Model and Reservoir Modelling

➢"A reservoir model is a consistent representation of all data and knowledge about a reservoir, relevant to the management of the reservoir"
➢"Reservoir modelling is the process of building and maintaining the reservoir model"

(*ROXAR, 2005*)

- Structural model and stratigraphic model
- Distributions of lithofacies and the petrophysical properties of the reservoir
- Initial distributions of fluids and pressure
- Dynamic fluid behaviour and properties

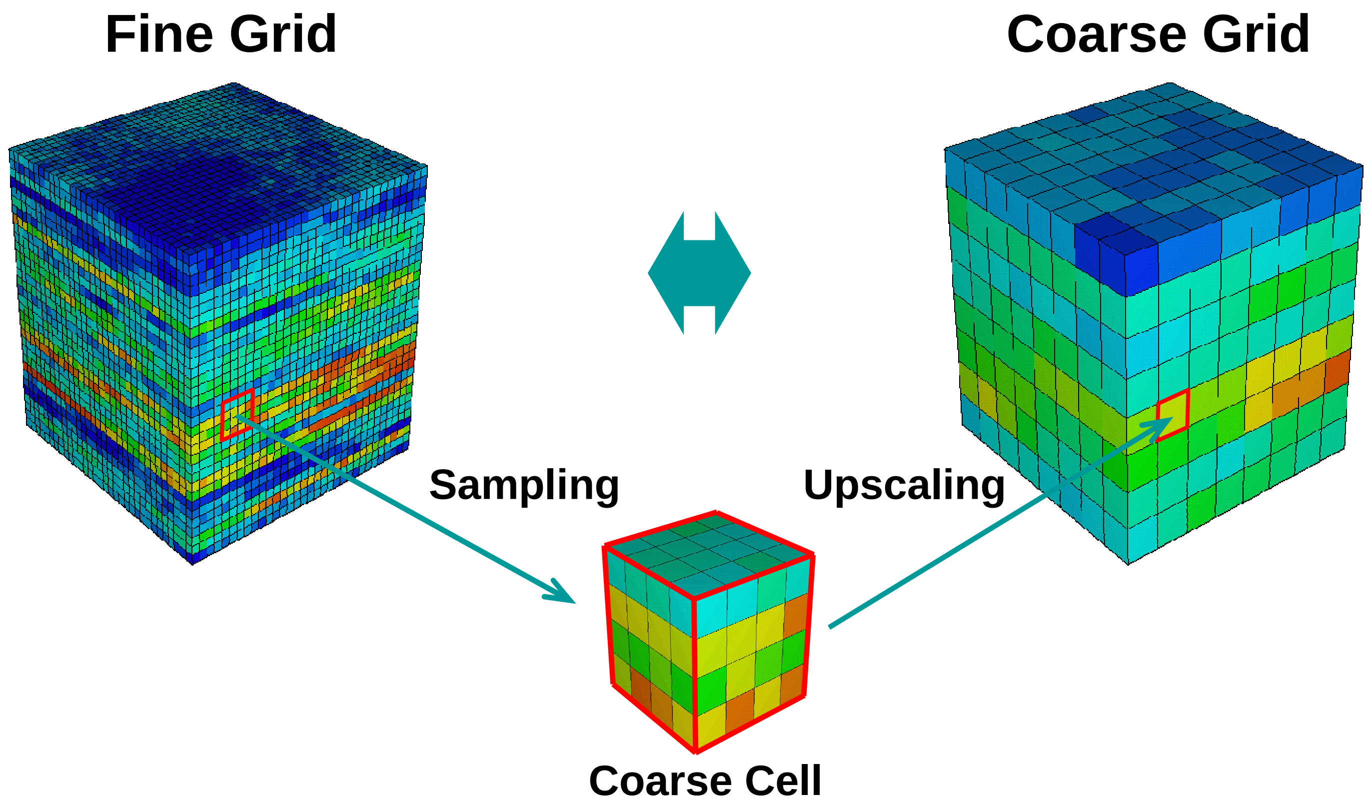


ROXAR, 2005

Spatial Interpolation Algorithm

- Discrete input (eg, lithofacies or sedimentary facies)
  - ✓Random field and stochastic simulation
  - ✓Pixel-based: Sequential indicator simulation, truncated Gaussian simulation, etc.
  - ✓Object-based: Random field, simulated annealing,…
- Continuous input (eg, petrophysical properties)
  - ✓Deterministic methods: moving average, various kriging techniques, etc.
  - ✓Stochastic simulation/co-simulation:
    - •Sequential Gaussian simulation
    - •Sequential indicator simulation
    - •Artificial intelligence
    - •Hybrid methodology: Artificial intelligence and geostatistics
- Constrained modelling
  - ✓Seismic attributes/facies
  - ✓Conceptual model: Facies model
  - ✓Well testing/production
- Computing with words
  - ✓IF-THEN rule

Reservoir Upscaling



➢*Reservoir property at the centre of coarse grid is able to effectively represent the distribution pattern of the property in the corresponding fine grids.*

4 Dynamic Reservoir Simulation

➢ **To assess the practical CO_2 storage capacity through dynamic reservoir simulation**

- ✓Trapping mechanisms of CO_2 storage in saline aquifer
- ✓Initial reservoir model: Rock and fluid properties
- ✓Full physics compositional simulation
- ✓Coupled simulation with geochemical reaction/transport, thermal effect, and geomechanical modelling
- ✓etc.

Trapping Mechanisms for CO_2 Storage in Saline Aquifer

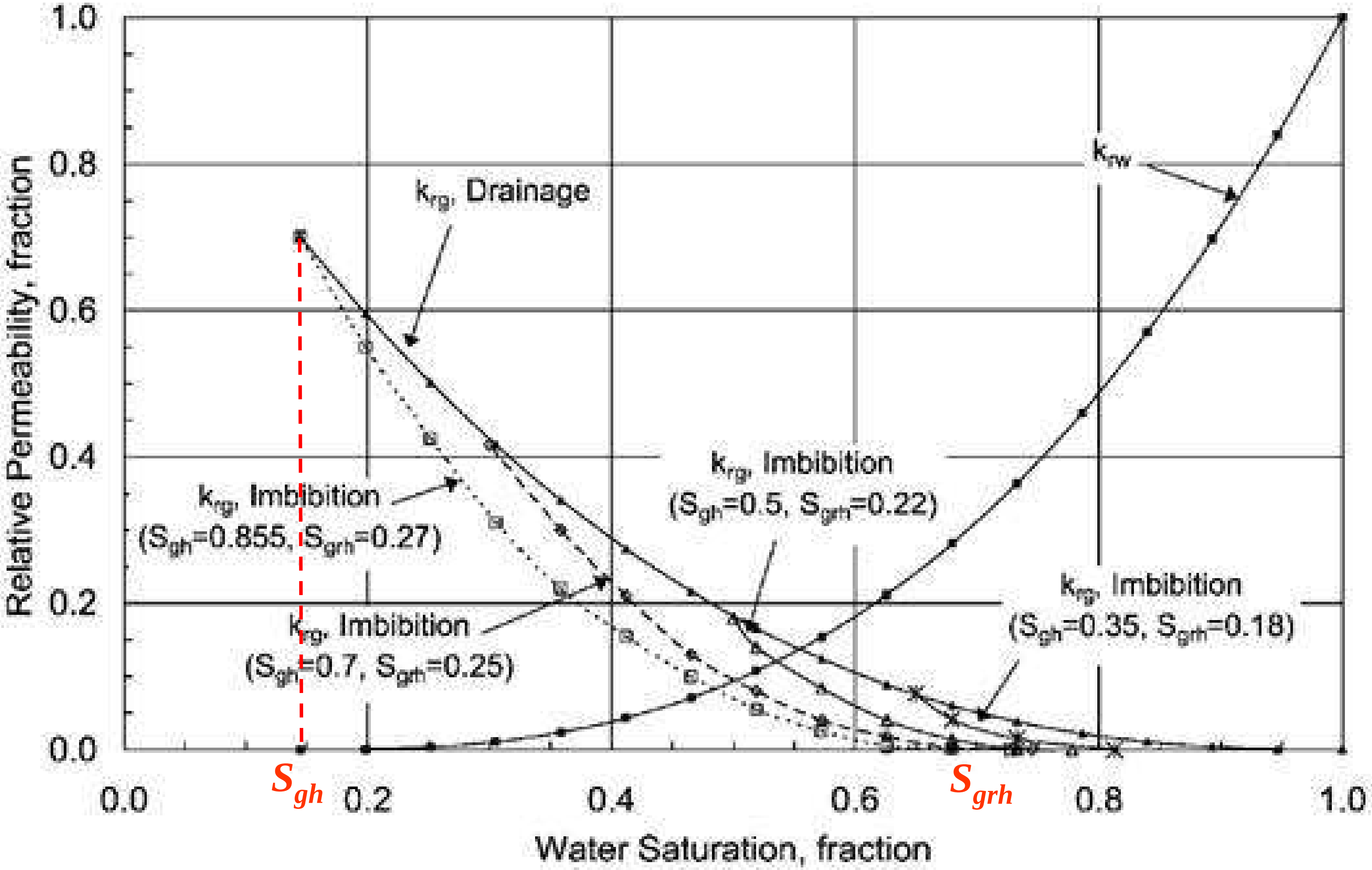
- **Hydrodynamic and structural trapping**
- **Solubility trapping**
  - ✓Storing CO_2 as a soluble component in brine
- **Residual gas trapping**
  - ✓Trapping as immobile residual gas (Sgrm)
- **Mineralization trapping**
  - ✓Water-rock interaction
  - ✓Long-term storage of green house gas

Initial Reservoir Condition

- Static reservoir grid model
- Initial reservoir temperature/gradient
- Initial reservoir pressure/gradient
- Fluid property:
  - ✓CO_2 and (brine) water
  - ✓Density, viscosity, compressibility
  - ✓Chemical composition of water
  - ✓Solubility of CO2: Equation of state (EOS, PR, SRK, SW, DS, etc.)
  - ✓Henry's law constant
- Relative permeability hysteresis
  - ✓Corey's model
  - ✓Land's equation and modified Land's equation
- Fracture pressure gradient
  - ✓Pre-frac/mini-frac
  - ✓(Extended) leak off test

Gas-Water Relative Permeability Hysteresis Model

CMG-GEM™ internal hysteresis model



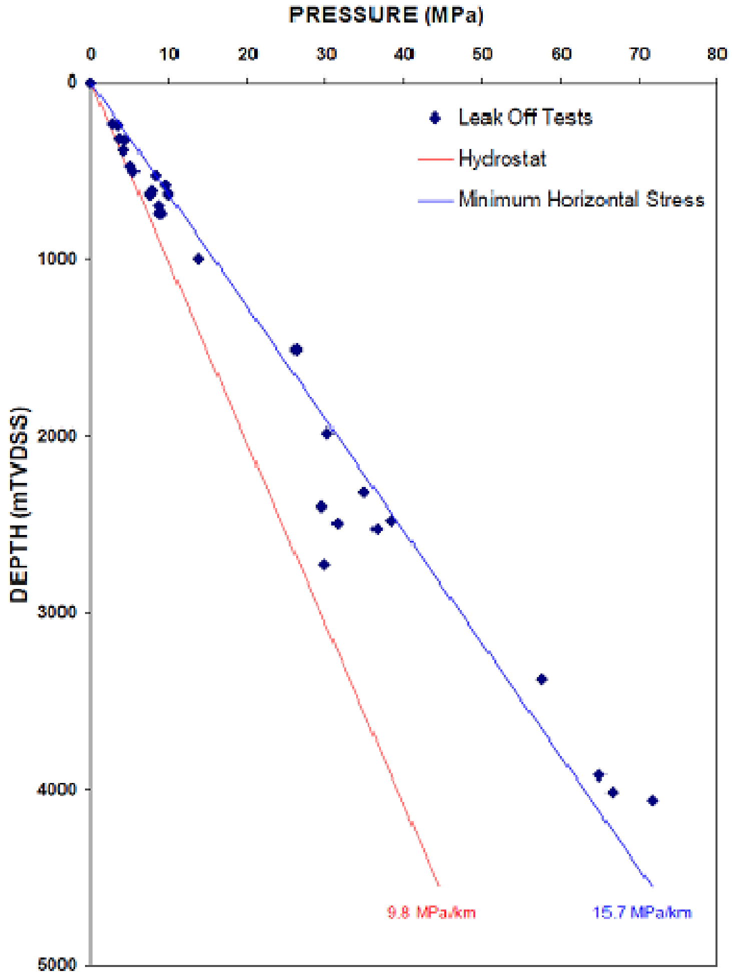
Kumar, et al., 2004

Injection Limits

- The **maximum injection rate** and the **maximum bottom hole pressure** are set as the limits for injection.

- The injection pressure or bottom hole pressure of the injection well should NOT be more than:

  - ✓Fracture pressure of reservoir top and cap rocks;
  - ✓Reactivation pressure of fault(s)
  - ✓BHPmax=Fracture Pressure × 0.9

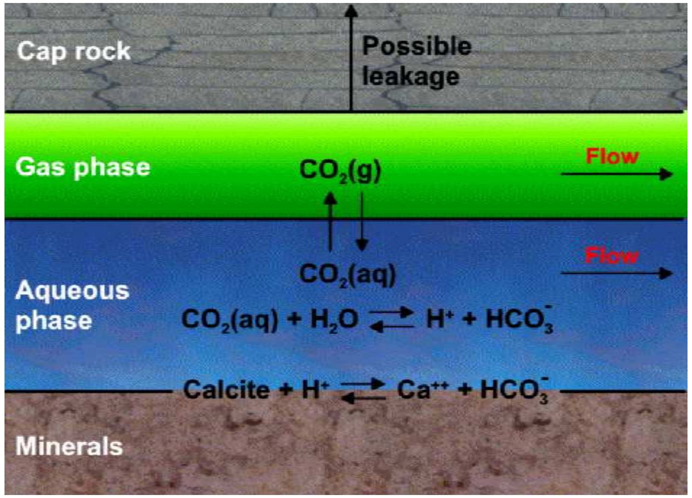


Integrated Compositional Simulation

- **Volume constraint equation**: the volume of fluids must equal the pore volume.
- **Component flow equations**: material balance equations for oil, gas and water components.
- **Energy balance equation** including convection, conduction and heat losses.
- **Phase equilibrium equations**.

Full-Physics Compositional Simulation

- Convective and dispersive flow
- Relative permeability hysteresis
- Gas solubility in aqueous phase
- Aqueous chemical equilibrium reactions
- Mineral dissolution and precipitation kinetics
- Vaporization of H_2O
- Predictions of brine density and viscosity
- Leakage through internal barrier and cap rock and thermal capability



CMG Training, 2008

Coupled Simulations

- Coupled simulation of fluid flow, geochemical reaction/transport and thermal effect
  - ✓ Fluid flow
  - ✓ Mineral dissolution and precipitation/mineralisation trapping
  - ✓ Thermal effects

- Coupled simulation of fluid flow and geomechanics

  - ✓ Fracturing and leakage risk of internal baffles or cap rocks
  - ✓ Reactivation of fault

Geochemical Reaction
Mineral Dissolution & Precipitation

$$\text{Calcite(solid)} + H^{+} = Ca^{++} + HCO_3^{-}$$

$$\frac{V}{\Delta t}(N_i^{n+1} - N_i^{n}) = r_i$$

$$r_i = V \cdot A \cdot k \cdot \left(1 - \frac{Q}{K_{eq}}\right)$$

$$Q = \frac{a_{Ca^{++}} \cdot a_{HCO_3^{-}}}{a_{H^{+}}}$$

V = bulk volume (m^3)

A = reactive surface area (m^2/m^3)

k = rate constant ($mol/m^2\ s$)

K_{eq} = chemical equilibrium constant

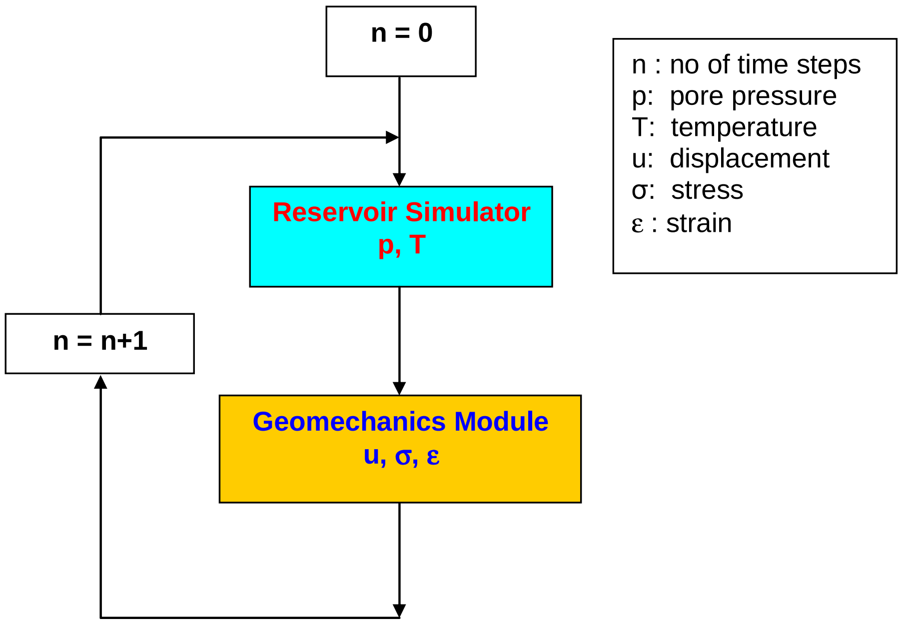
Q/K_{eq} = saturation index

$Q/K_{eq} > 1 \rightarrow$ mineral precipitation

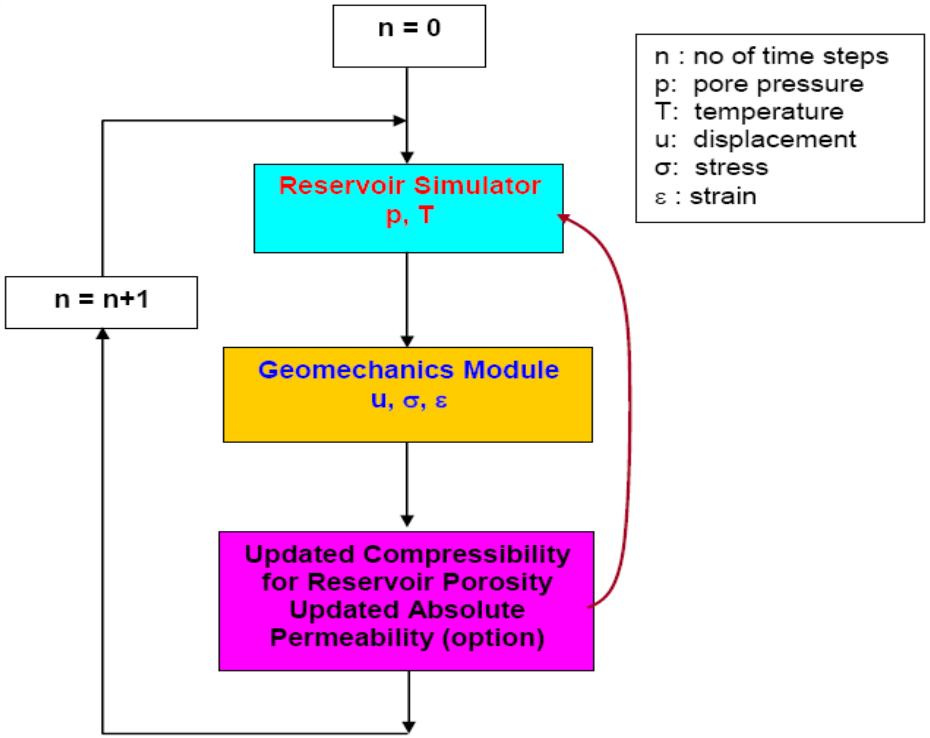
$Q/K_{eq} < 1 \rightarrow$ mineral dissolution

Geomechanical Simulation Coupled with Compositional Simulator

- **Finite element approach:**



One Way Coupling Simulation



Two Way Coupling Simulation

(CMG, 2009)

5 Remarks

- Modified invasion percolation method in basin modelling can be used to assess the theoretical carbon storage potential with basin scale.
- For the purpose of site characterisation and assessment of CO_2 storage capacity in reservoir scale, the integrated reservoir study is required, including basin and reservoir geology, seismic interpretation, log interpretation and correlation, velocity modelling and time-depth conversion, 3D grid construction, lithofacies and petrophysical modelling, reservoir upscaling, and reservoir dynamic simulation.
- Coupled simulations are able to provide information on CO2 plume movement, effective storage capacity together with changes of minerals of rock, chemical properties (ions) of brine water and petrophysical properties.
- Besides the effective storage capacity assessment, the coupled simulation can provide the information of changes of stress and strain, the risks of caprock leakage and fault reactivation.