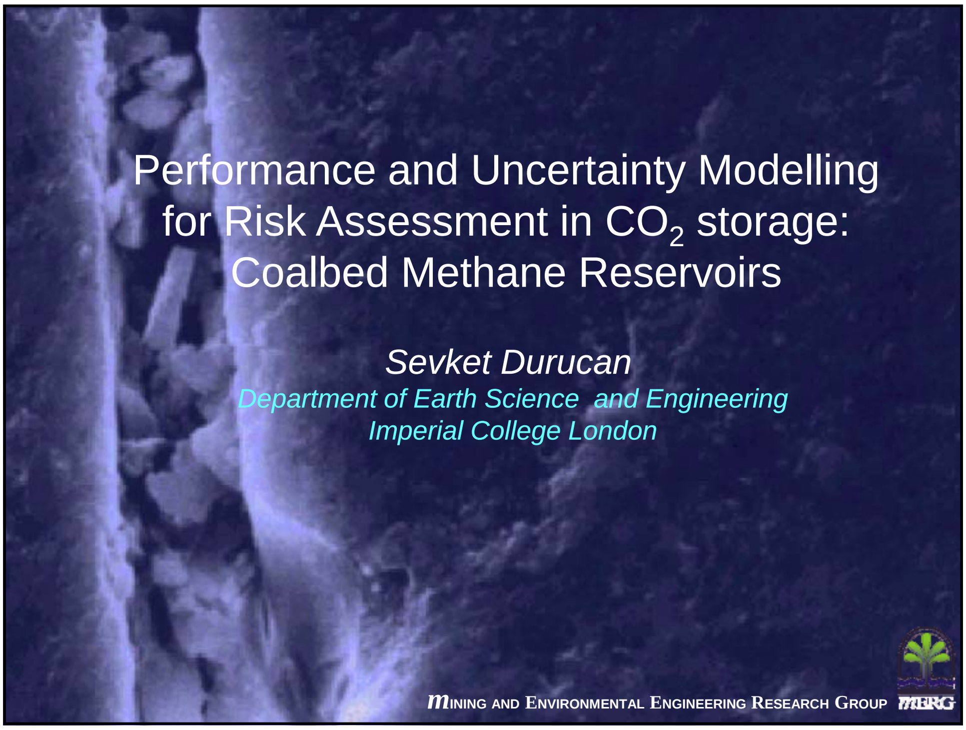

Performance and Uncertainty Modelling for Risk Assessment in CO_2 storage: Coalbed Methane Reservoirs

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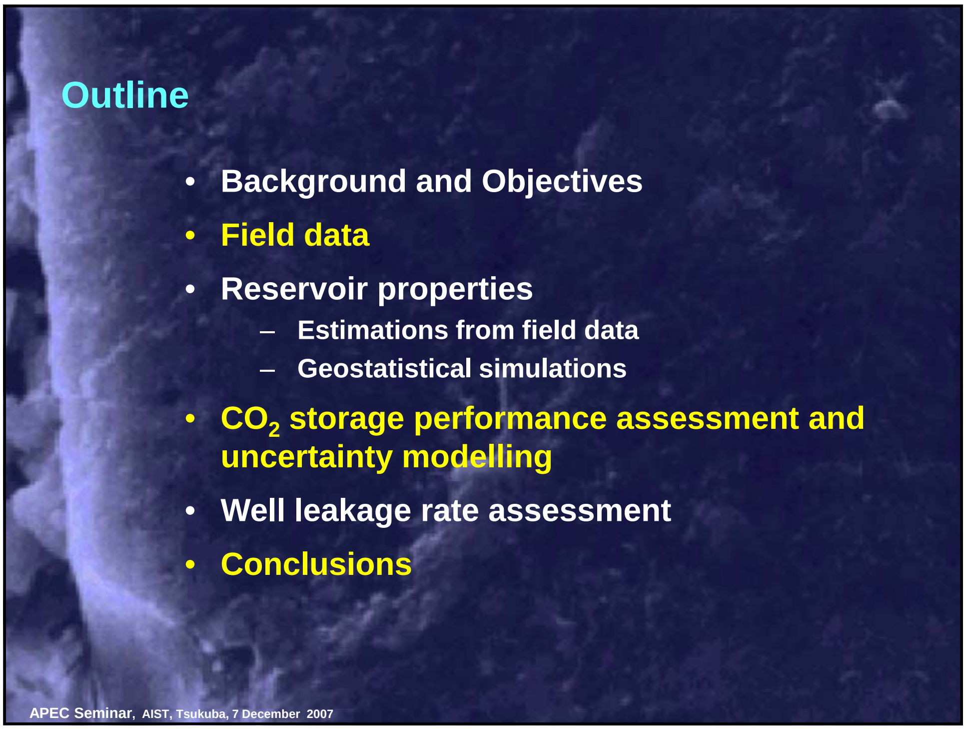


Outline

- **Background and Objectives**
- **Field data**
- **Reservoir properties**
  - **Estimations from field data**
  - **Geostatistical simulations**
- **CO_2 storage performance assessment and uncertainty modelling**
- **Well leakage rate assessment**
- **Conclusions**

Background

Coal seam reservoir parameters exhibit large spatial and temporal heterogeneity, with possible variations of up to one or more orders of magnitude within a short distance or time.

These properties do not vary in space in a purely random fashion and there is some structure to the spatial variability. This can be characterised in a statistical way using geostatistical methods.

The temporal variability of some of these parameters is usually linked to the reservoir processes taking place over time (such as stress/pore pressure dependent permeability), can be defined and be predicted within the reservoir models used.

Sources of Uncertainty in CO_2 Storage Risk Assessment

Data uncertainty and variability, being the lack of accurate knowledge and representation of heterogeneity in the measured data.

Reservoir parameter uncertainty, frequently, there are large spatial and temporal variations in some of these parameters that are used to represent the physical processes in the models. (porosity, sorption capacity, permeability, diffusion coefficients, etc.).

Modelling uncertainty, which has to do with the true knowledge and understanding of the physics of the storage process and its representation in the mathematical models used (the use of different sorption, diffusion and permeability models).

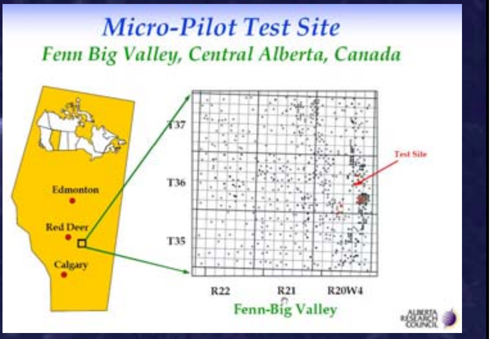
Risk scenario uncertainty, which is related to the long term future of the reservoir and includes long term processes.

Objective

The main objective of our research in this field is to establish a quantitative methodology towards the estimation of risk and uncertainty in geological storage of CO_2.

The modelling of uncertainty due to permeability heterogeneity in the reservoir and the effect of well leakage rate on CO_2 storage are described here.

This study used field data from the IHS Energy (well data), the Natural Resources Canada (geological model), and Alberta Research Council (ARC) (micro-pilots results in the Fenn Valley, Alberta)



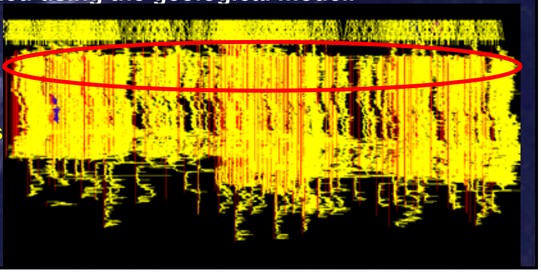
Field Data

The coal seams targeted were the Mannville coals in Alberta.

The digital geological model for the region, developed using seismic and well log information at a resolution of 250m grid, was provided by Natural Resources Canada.

Digital well log data for 425 wells covering a surface area of approximately 2,500 km^2 were provided by IHS Energy. The wire line logs included Gamma Ray, Neutron, Density, Acoustic and the Resistivity logs.

The coal strata were identified based on three logs, the Gamma Ray, Neutron and the Density, and were confirmed using the geological model.



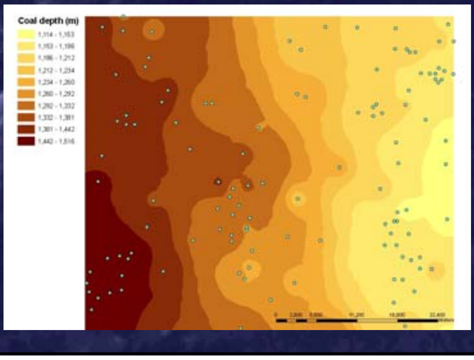
Gamma Ray logs for 425 wells indicating zone of interest

Field Data

Only 129 wells had these three logs in the formation of interest. These were further used for evaluating the reservoir properties (seam thickness and permeability) used in simulations.

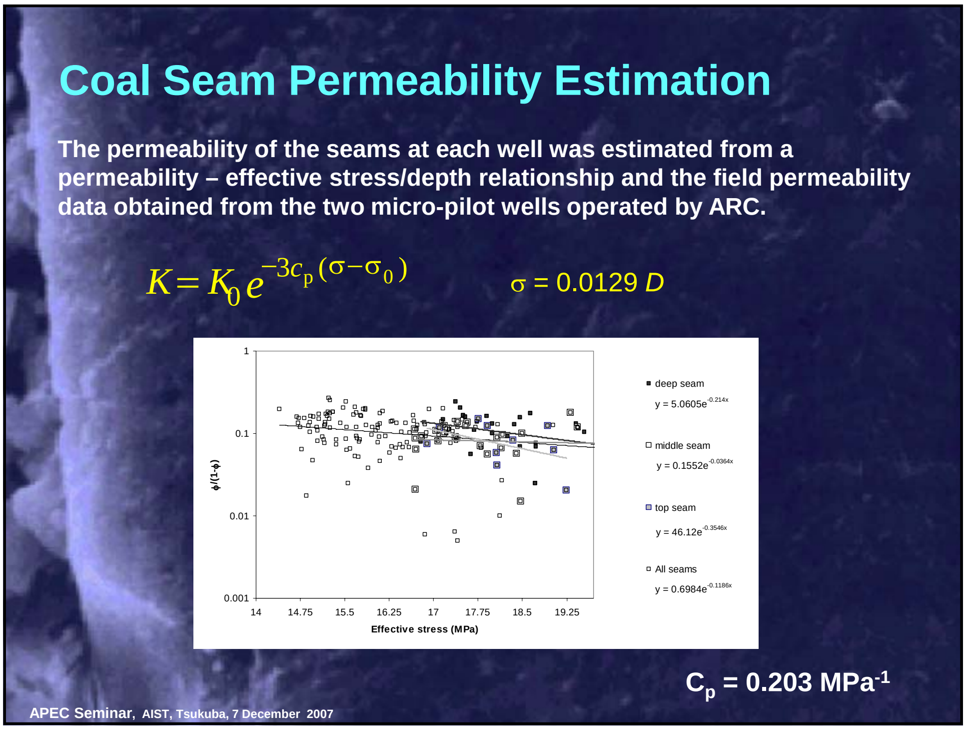
The top of the formations identified by the well logger was used as a reference to locate the depth of interest.

Total porosity was calculated from the acoustic logs.



Locations of wells and depth of upper coal seams.

Assessment of the uncertainty related to the coalbed reservoir properties and their spatial distribution



Coal Seam Permeability Estimation

The permeability of the seams at each well was estimated from a permeability – effective stress/depth relationship and the field permeability data obtained from the two micro-pilot wells operated by ARC.

$$K = K_0 e^{-3c_p(\sigma - \sigma_0)} \qquad \sigma = 0.0129\,D$$

C_p = 0.203 MPa^{-1}

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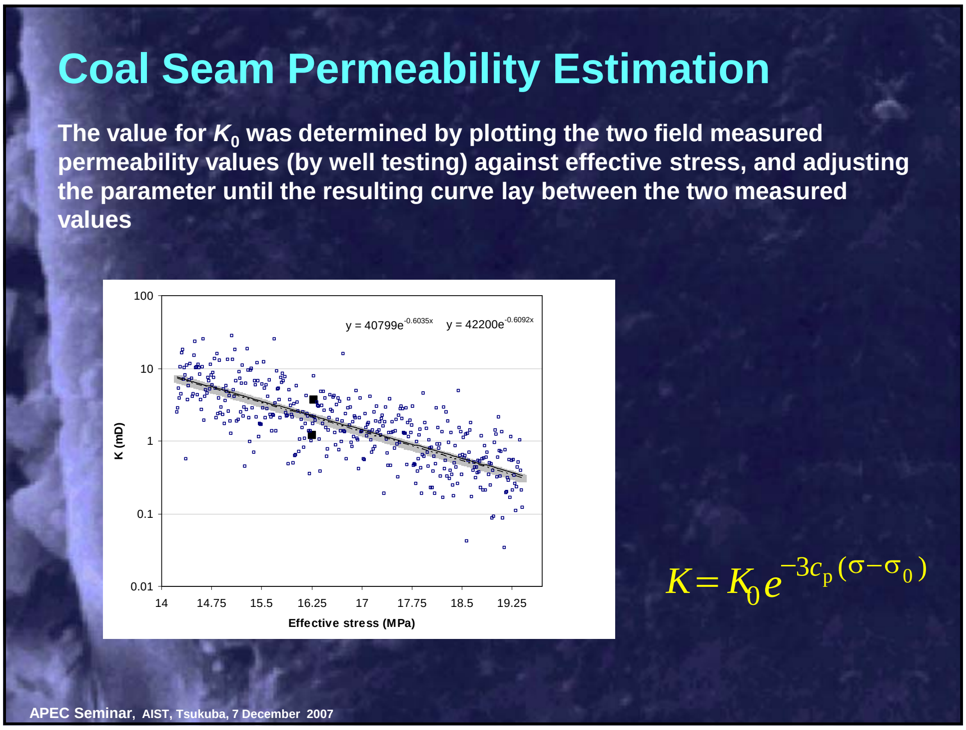

Coal Seam Permeability Estimation

The value for K_0 was determined by plotting the two field measured permeability values (by well testing) against effective stress, and adjusting the parameter until the resulting curve lay between the two measured values

$$K = K_0 e^{-3c_p(\sigma - \sigma_0)}$$

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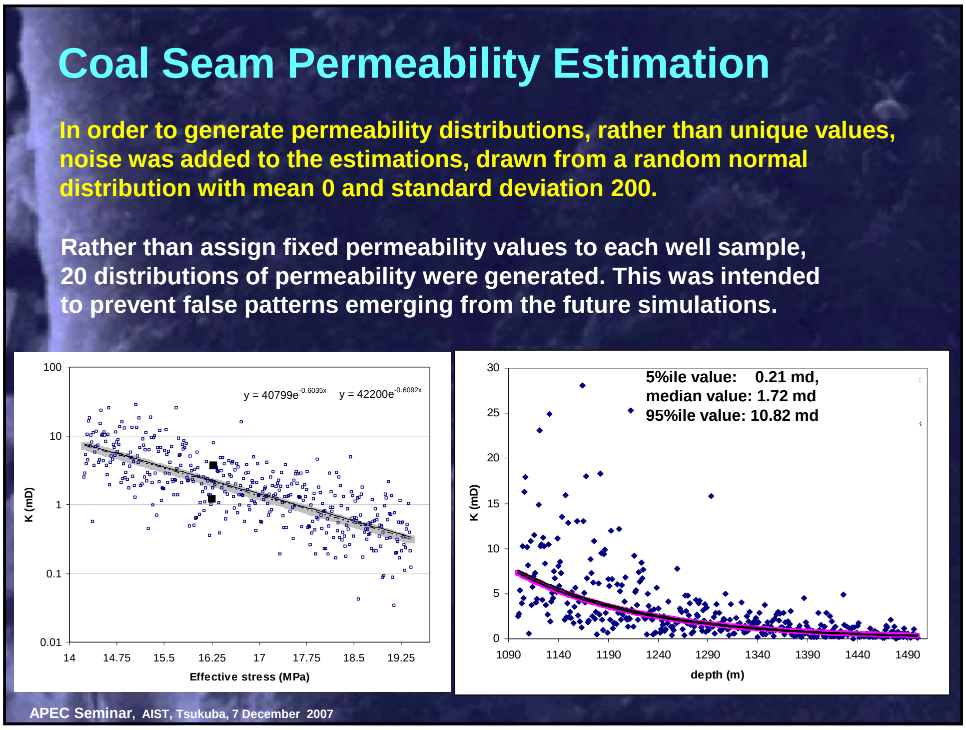

Coal Seam Permeability Estimation

In order to generate permeability distributions, rather than unique values, noise was added to the estimations, drawn from a random normal distribution with mean 0 and standard deviation 200.

Rather than assign fixed permeability values to each well sample, 20 distributions of permeability were generated. This was intended to prevent false patterns emerging from the future simulations.

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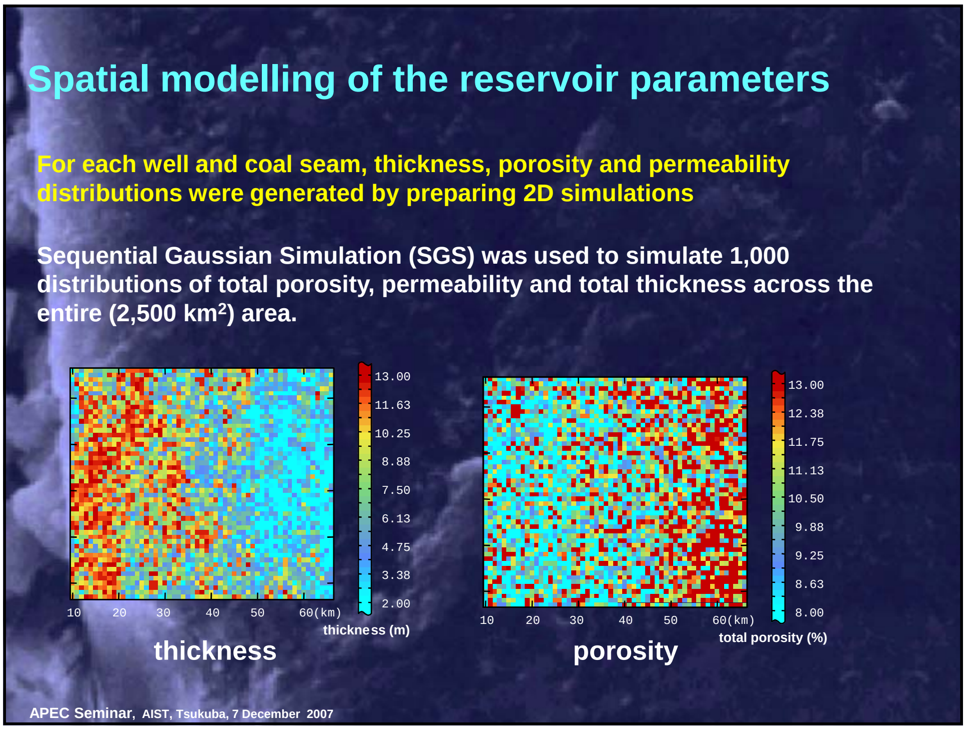

Spatial modelling of the reservoir parameters

For each well and coal seam, thickness, porosity and permeability distributions were generated by preparing 2D simulations

Sequential Gaussian Simulation (SGS) was used to simulate 1,000 distributions of total porosity, permeability and total thickness across the entire (2,500 km^2) area.

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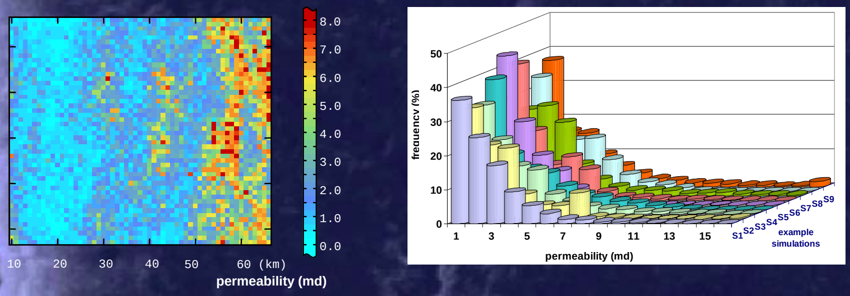
Spatial modelling of the reservoir parameters



Spatial permeability distribution and permeability histogram for the whole site

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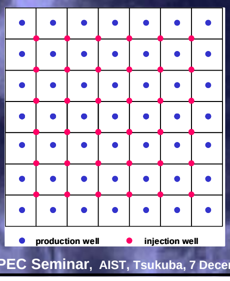
Reservoir parameter uncertainty and CO_2 storage performance assessment

An area of approximately 3.5 x 3.5Km (3,027 acres) surrounding the two ARC micro-pilots was selected, over which a number of permeability realisations were generated over a 2D grid of 57 x 57 cells with 36 CO_2 injectors and 49 CH_4 producers.

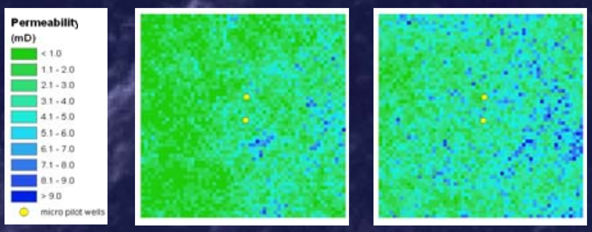
The permeabilities were obtained using conditional SGS and the simulations were constrained using the two measured permeabilities from the micro-pilots.

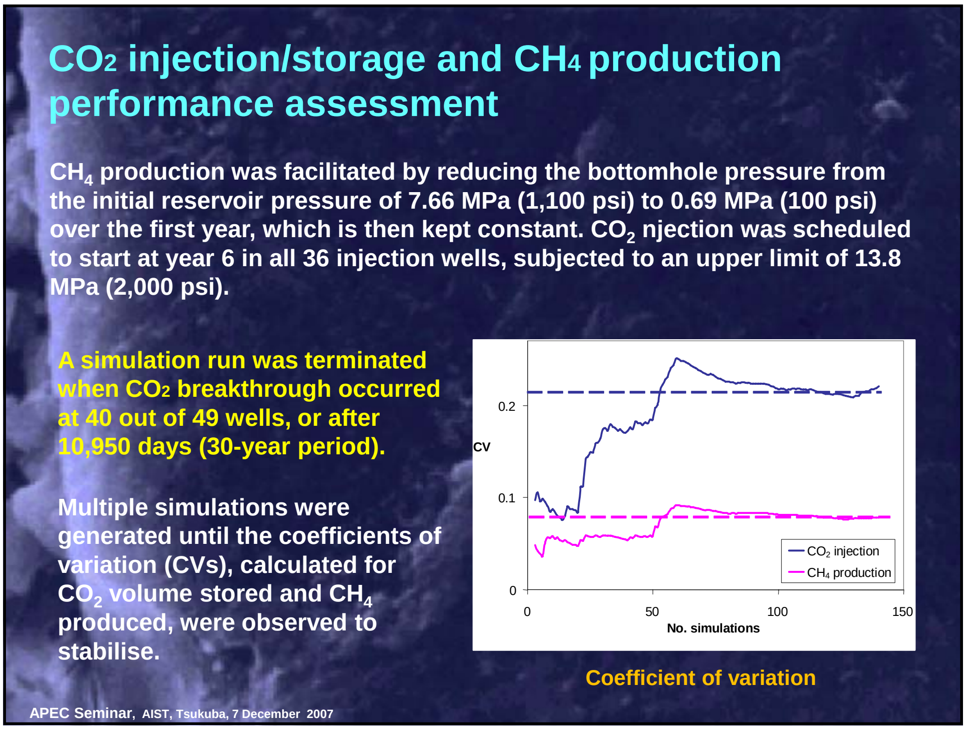
The net thickness and porosity values for each grid cell were kept fixed. These were obtained by kriging over the grid, based on measurements made at wells located within the ranges of the respective variograms.

Well layout



Permeability realisations





CO_2 injection/storage and CH_4 production performance assessment

CH_4 production was facilitated by reducing the bottomhole pressure from the initial reservoir pressure of 7.66 MPa (1,100 psi) to 0.69 MPa (100 psi) over the first year, which is then kept constant. CO_2 njection was scheduled to start at year 6 in all 36 injection wells, subjected to an upper limit of 13.8 MPa (2,000 psi).

A simulation run was terminated when CO_2 breakthrough occurred at 40 out of 49 wells, or after 10,950 days (30-year period).

Multiple simulations were generated until the coefficients of variation (CVs), calculated for CO_2 volume stored and CH_4 produced, were observed to stabilise.

Coefficient of variation

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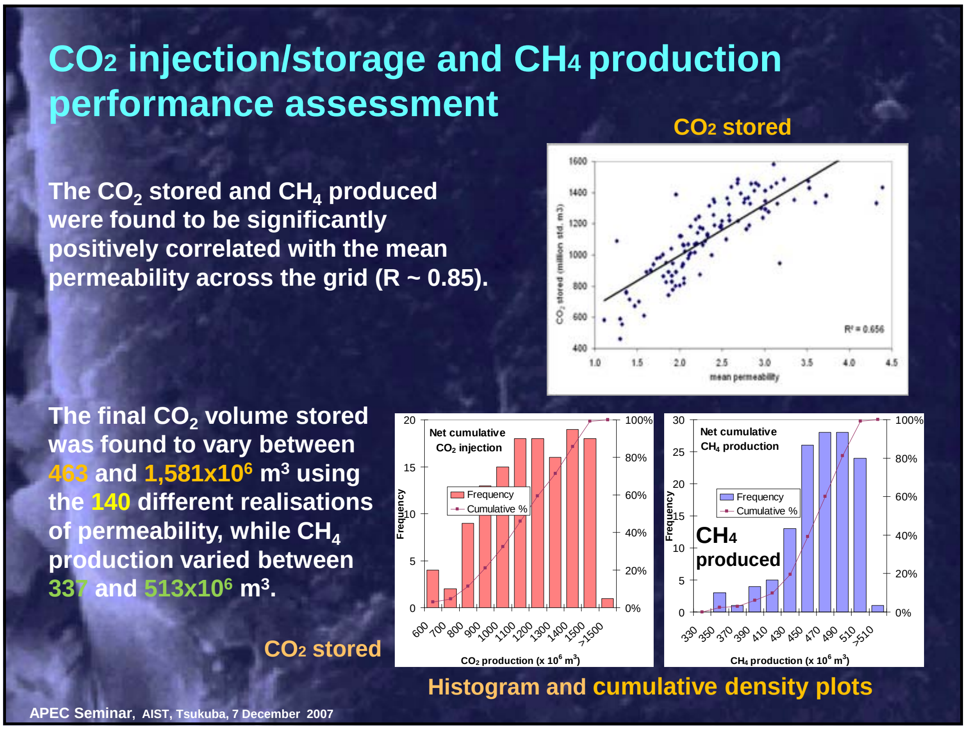

CO_2 injection/storage and CH_4 production performance assessment

The CO_2 stored and CH_4 produced were found to be significantly positively correlated with the mean permeability across the grid (R ~ 0.85).

CO_2 stored

The final CO_2 volume stored was found to vary between 463 and 1,581x10^6 m^3 using the 140 different realisations of permeability, while CH_4 production varied between 337 and 513x10^6 m^3.

CO_2 stored

Histogram and cumulative density plots

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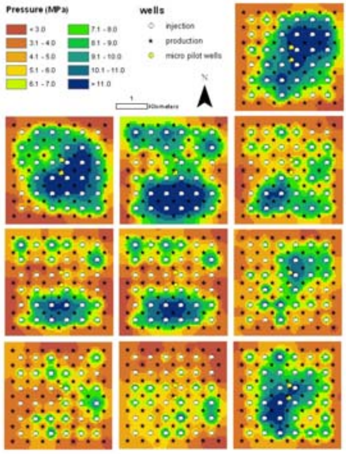
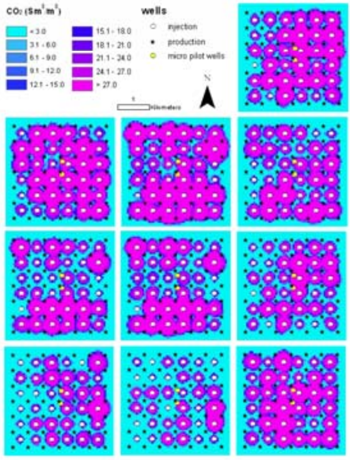
CO_2 injection/storage and CH_4 production performance assessment

Results of 10 selected simulations across the range



Reservoir pressure



Unit CO_2 stored

Risk scenario uncertainty modelling

The ultimate objective of risk assessment in CO_2 storage is to generate reservoir simulations that would allow accurate predictions of future reservoir performance, including the use of the confidence intervals of these forecasts to establish risk scenario uncertainty.

In order to assess CO_2 leakage through sealed injection/production wells in the long term reservoir simulations, it is essential to set the physical leakage rates that may occur.

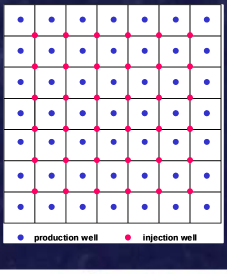
Many containment risk assessments are benchmarked against an impact of 1% leakage of total gas stored over 1,000 years, therefore, the frequency and volume of potential leakage events were assessed for this time frame.

Well leakage assessment

Well leakage rate is controlled by cement permeability and prevailing reservoir pressure.

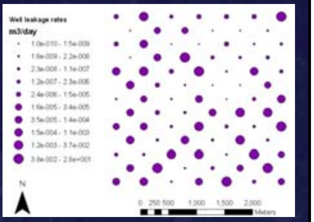
Well cement permeability falls in a wide range from10^{-5} md (well-formed cement) to 10^{4} md (significant leakage may occur).

The possible well cement permeabilities for the 85 wells are randomly selected from a lognormal cement permeability distribution.



A nominal leakage rate (e.g. 1% of stored volume over 1000 years) is assigned to the well with the largest cement permeability, at a given reservoir pressure

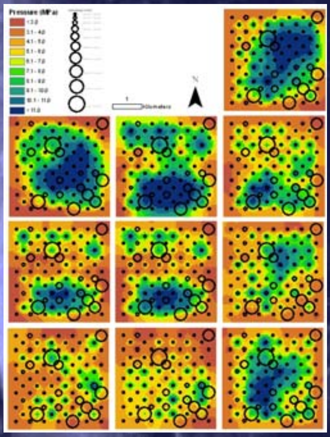
The leakage rates from the other wells in the model are determined accordingly depending on their well cement permeability (relative to the highest well value) and dynamic (local) reservoir pressure.



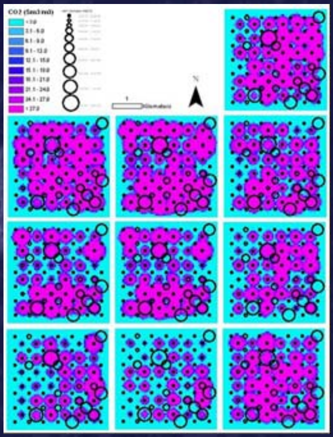
Distribution of well leakage rate for one realisation

Well leakage rate assessment – simulation results (1)

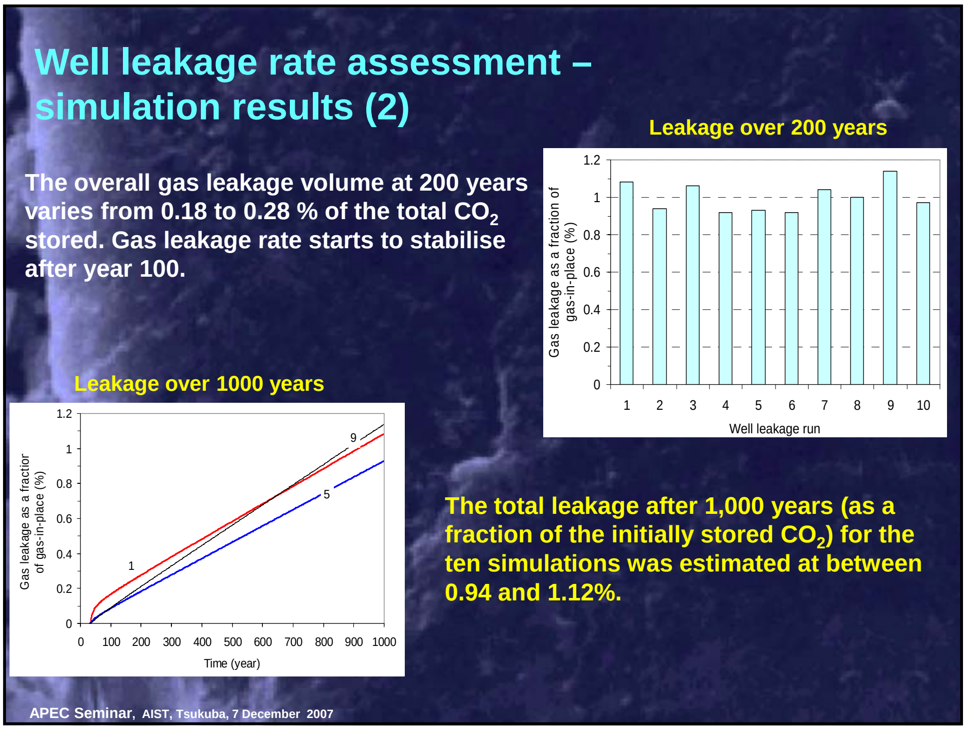
One well leakage rate realisation superimposed on maps of simulated reservoir pressure and CO_2 stored for 10 selected simulations



Reservoir pressure



Unit CO_2 stored



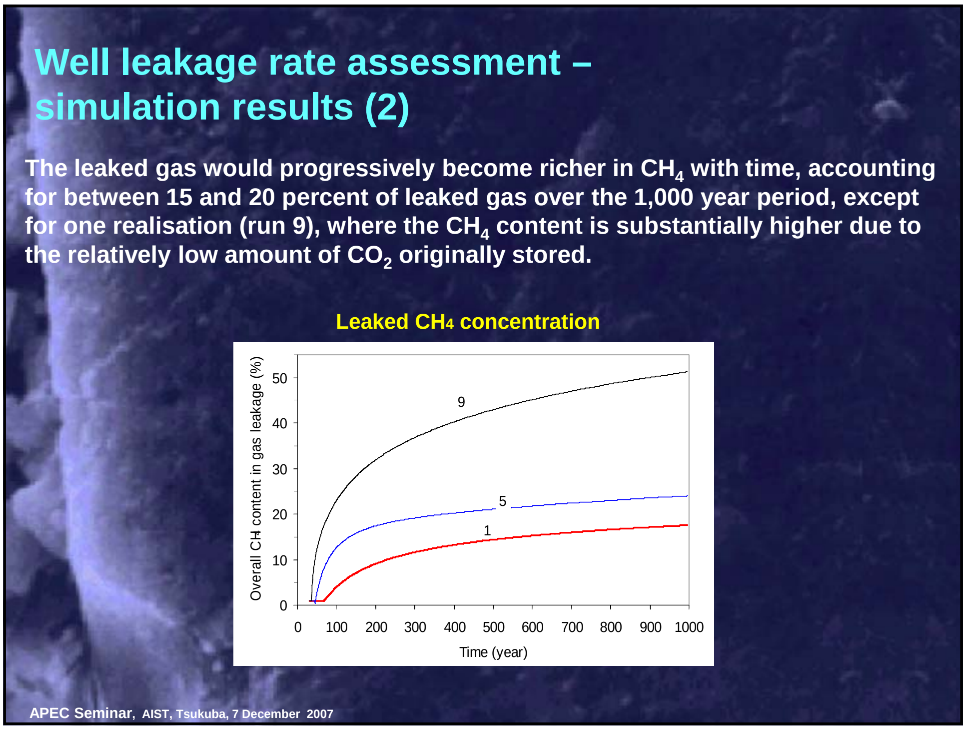
Well leakage rate assessment – simulation results (2)

The overall gas leakage volume at 200 years varies from 0.18 to 0.28 % of the total CO_2 stored. Gas leakage rate starts to stabilise after year 100.

Leakage over 200 years

Leakage over 1000 years

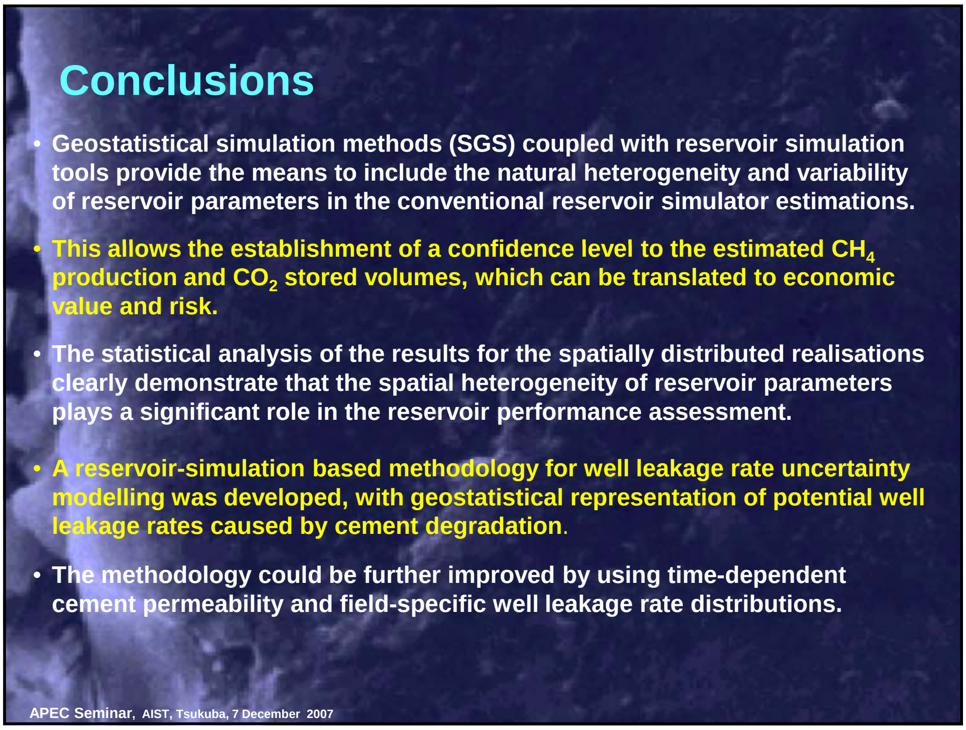
The total leakage after 1,000 years (as a fraction of the initially stored CO_2) for the ten simulations was estimated at between 0.94 and 1.12%.



Well leakage rate assessment – simulation results (2)

The leaked gas would progressively become richer in CH_4 with time, accounting for between 15 and 20 percent of leaked gas over the 1,000 year period, except for one realisation (run 9), where the CH_4 content is substantially higher due to the relatively low amount of CO_2 originally stored.

Leaked CH_4 concentration



Conclusions

- Geostatistical simulation methods (SGS) coupled with reservoir simulation tools provide the means to include the natural heterogeneity and variability of reservoir parameters in the conventional reservoir simulator estimations.
- This allows the establishment of a confidence level to the estimated CH_4 production and CO_2 stored volumes, which can be translated to economic value and risk.
- The statistical analysis of the results for the spatially distributed realisations clearly demonstrate that the spatial heterogeneity of reservoir parameters plays a significant role in the reservoir performance assessment.
- A reservoir-simulation based methodology for well leakage rate uncertainty modelling was developed, with geostatistical representation of potential well leakage rates caused by cement degradation.
- The methodology could be further improved by using time-dependent cement permeability and field-specific well leakage rate distributions.