An Experimental Study on the Flood Characteristic and Fluid Rock Interactions of a Supercritical CO_2, Brine, Rock System*

Ali Saeedi[1], Claudio Delle Piane[2], Lionel Esteban[2], Linda Stalker[2]

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Abstract

The South West Hub Project is an Australian government-funded initiative in partnership with major local industrial CO_2 emitters. The project aims to reduce emissions by storing commercial quantities of CO_2 in a deep saline aquifer, the Triassic Lesueur Sandstone, located in the Perth Basin of Western Australia. This research investigated the multiphase flow characteristics of the Supercritical CO_2 (scCO2)-brine-rock system pertinent to the potential storage interval. Core-flooding experiments were conducted on four representative core plugs from the Harvey-1well. The experiments were performed using a conventional unsteady-state procedure to obtain relative permeability and residual saturation measurements. Fluids used during the experimental work consisted of dead formation brine, CO_2-saturated brine and vapour-saturated scCO2. Experimental pressure, temperature and brine salinity values were chosen to match the in-situ ones at the sample depths. Petrophysical measurements were carried out on the samples before and after core-flooding (i.e. helium porosity-permeability; pore size distribution by nuclear magnetic resonance (NMR); microstructural and mineralogical investigations) to assess any potential alteration of the samples induced by the flooding procedure. Results show that porosity is not affected by the flooding procedure, but permeability values significantly differ before and after flooding, causing reductions of 25% to 60%. Formation damage (e.g., fines migration) caused by presence of clay minerals in sample pore space may induce unusually low end-point relative permeability values measured at the end of the primary imbibitions. The fines migration hypothesis is supported by NMR measurements performed on two of the samples before and after core-flooding. These indicate a negligible variation of total porosity (also indicated by Helium measurements), but a significant difference in the distribution of pore size compatible

with the occlusion of larger pores by the fines dislodged by the fluids flowing through the pore space. Note that the migration of any fines, which may result in blockage and/or bridging of the pore throats, may intensify the snap-off trapping mechanism and consequently cause residual scCO2 saturation measurements to be abnormally high. The residual scCO2 saturations for all the samples tested here are within the range of 23%–43% which are to some extent higher than expected for their respective permeability ranges.

Reference Cited

Delle Piane, C., H.K.H. Olierook N.E. Timms, A. Saeedi, L. Esteban, R. Rezaee, V. Mikhaltsevitch, S. Iglauer, and M. Lebedev, 2013, Facies-baed rock properties distribution along the Harvey 1 stratigraphic well. Report to ANLEC R&D 7-1111-0199; 2013. Website accessed December 6, 2015, www.anlecrd.com.au.

Olierook, H.K.H. C. Delle Piane, N.E. Timms, L. Esteban, R. Rezaee, and A.J. Mory, 2014, Facies-based rock properties characterization for CO2 sequestration: GSWA Harvey 1 well, Western Australia: Marine and Petroleum Geology, v. 50, p. 83-102.

Stalker, L., R. Noble, D. Gray, C. Trefry, S. Varma, A. Ross, S. Sestak, S. Armand, and S. Gong, 2013, Geochemical characterisation of gases, fluids and rocks in the Harvey-1 data well. Report to ANLEC R&D 7-1111-0200; 2013. Website accessed December 6, 2015, http://www.anlecrd.com.au.

Stalker, L., D. Van Dent, S. Sharma, and M. Burke, 2015 South West Hub CCS Project: Site characterisation and latest results (abstract): Search and Discovery Article #90217 (2015). Website accessed December 6, 2015, http://www.searchanddiscovery.com/abstracts/html/2015/90217ice/abstracts/2202261.html.

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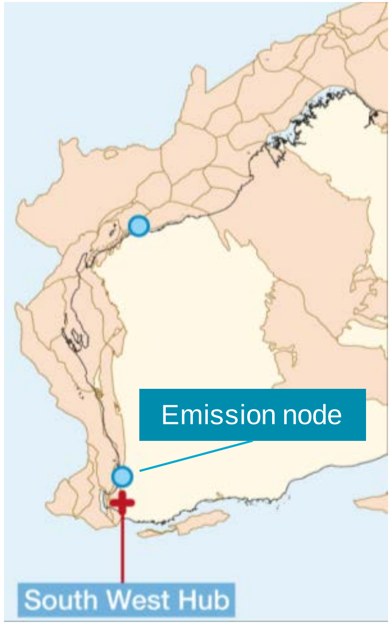
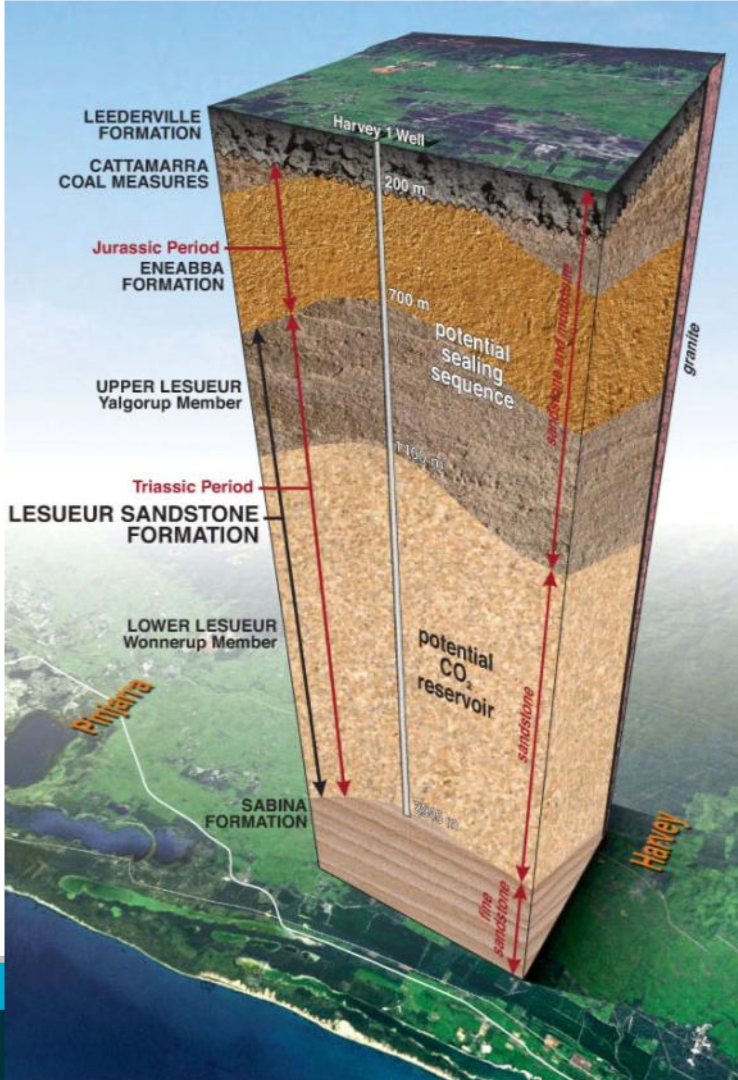
[a] Curtin University; [b] CSIRO Energy

Intro

South West Hub Project*: Government funded initiative aiming to reduce emissions by storing commercial quantities of CO_2 in a deep saline aquifer

Triassic **Lesueur Sandstone**, located in the Perth Basin of Western Australia

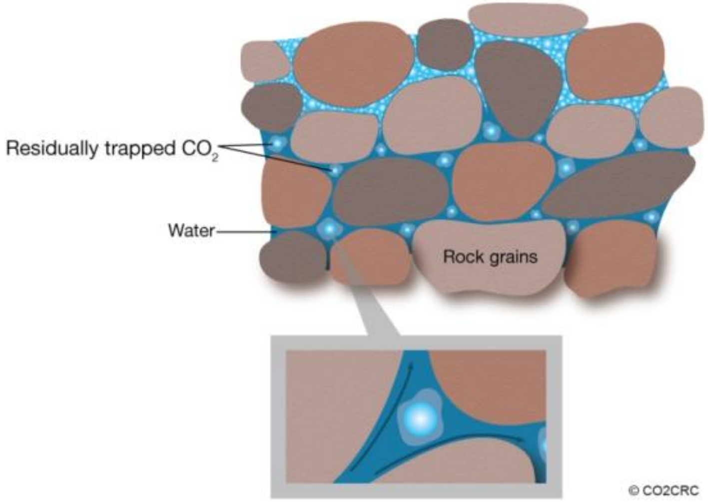




* Stalker et al. (2015)

Motivation and methodology

➢ Project is focused on residual trapping (trapping of CO_2 blobs by capillary forces)



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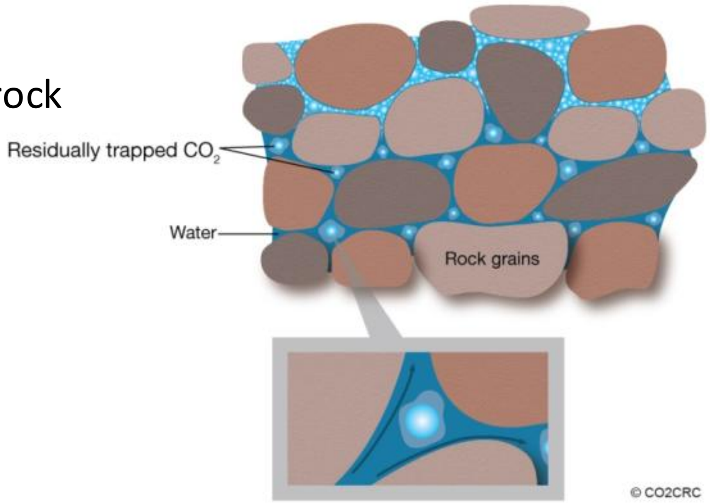
- Focus on multiphase flow characteristics of the $scCO_2$-brine-rock system



Motivation and methodology

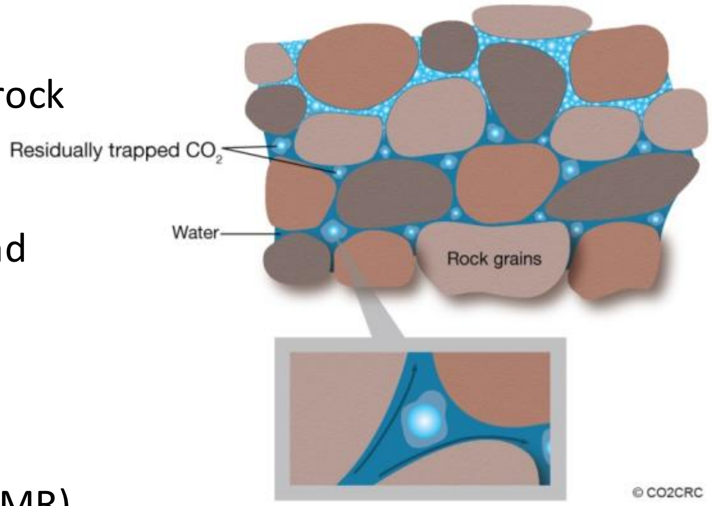
- Project is focused on residual trapping (trapping of CO_2 blobs by capillary forces)

- Focus on multiphase flow characteristics of the $scCO_2$-brine-rock system

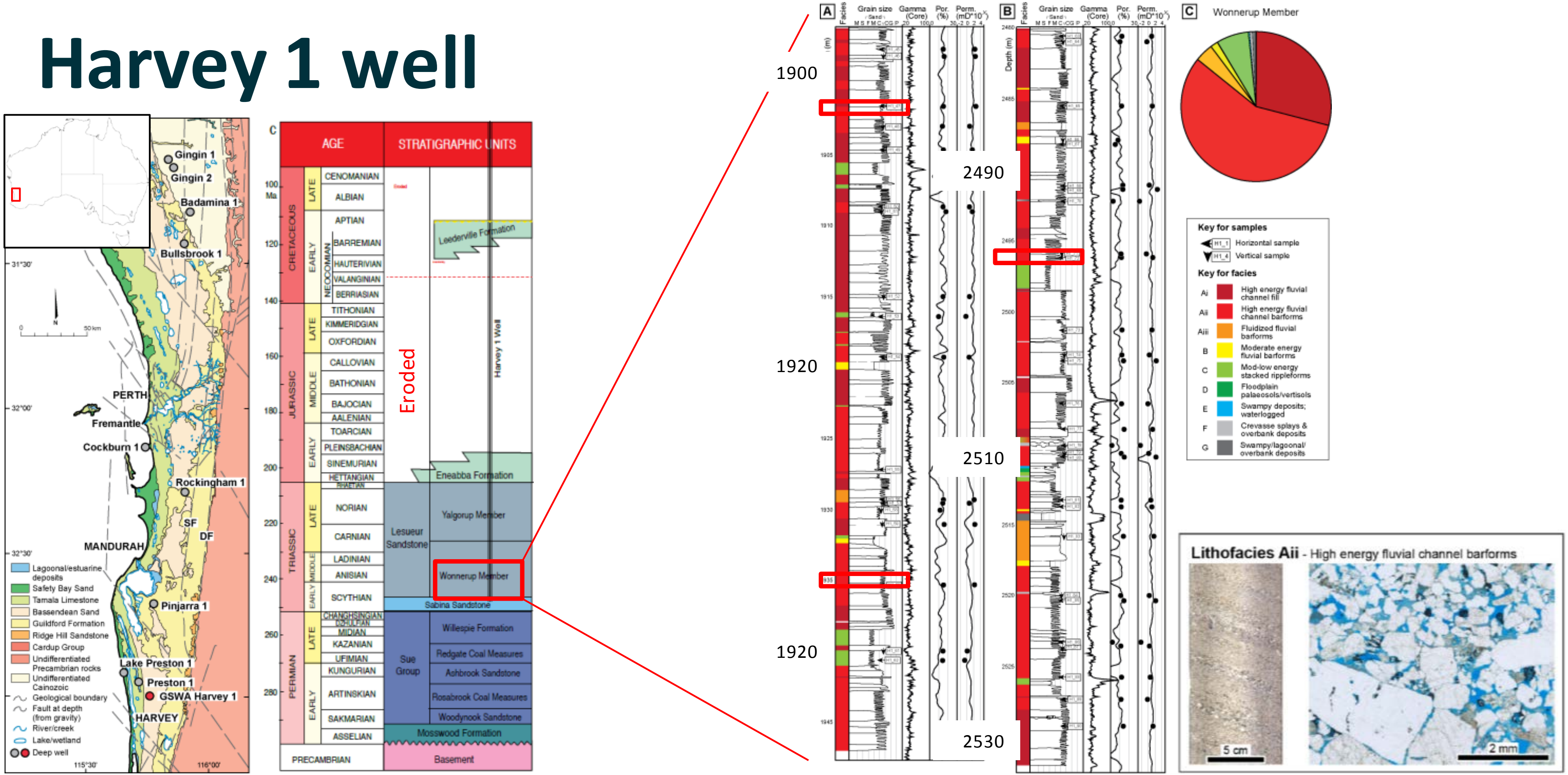
- Core-flooding experiments to obtain relative permeability and residual saturation measurements

- Petrophysical measurements before and after core-flooding:
    - Gas porosity-permeability;
    - Pore-size distribution by nuclear magnetic resonance (NMR)

- Microstructural and mineralogical characterization

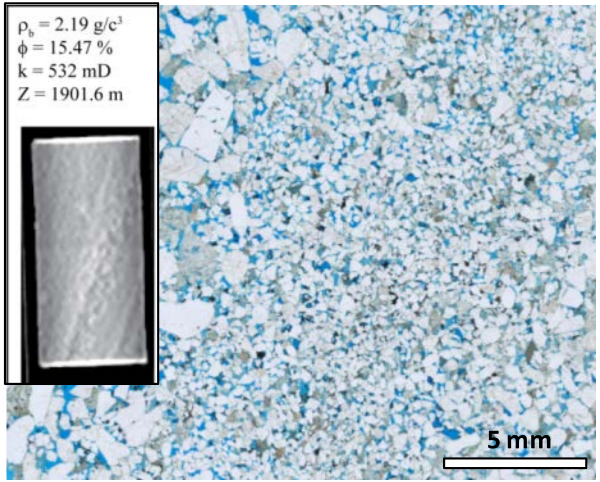


Harvey 1 well

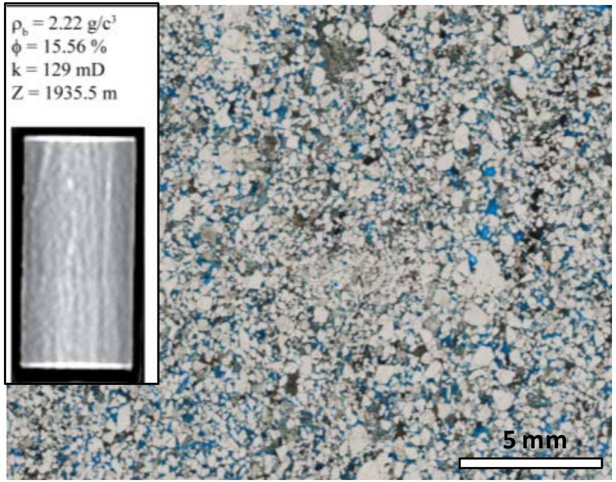


Olierook et al., 2014

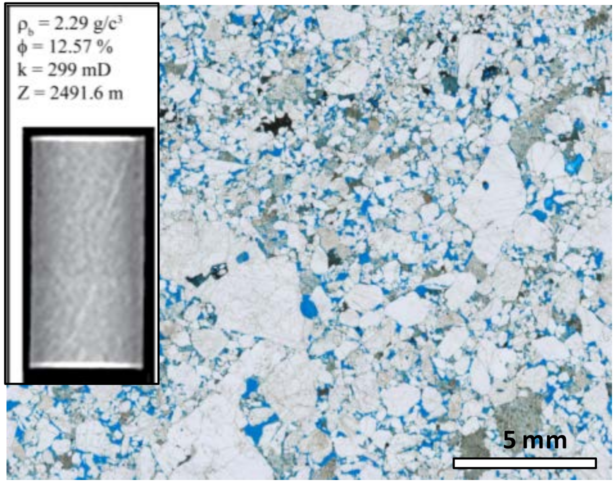
Samples



XRD Mineralogy (wt %)		
Quartz	K-feldspar	Kaolin
86	10	4

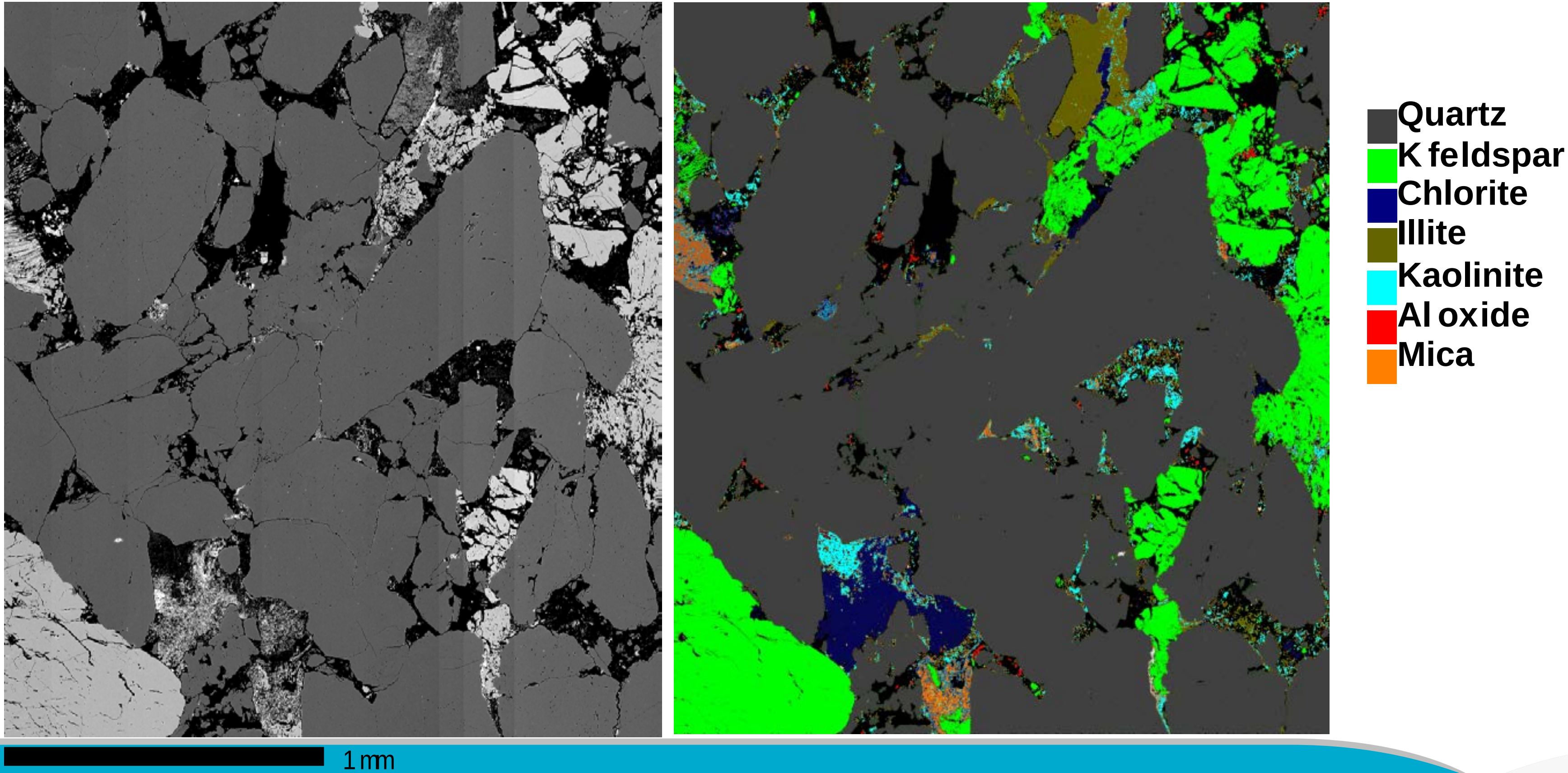


XRD Mineralogy (wt %)			
Quartz	K-feldspar	Ankerite	Kaolin
77	12	4	7



XRD Mineralogy (wt%)		
Quartz	K-feldspar	Kaolin
90	8	2

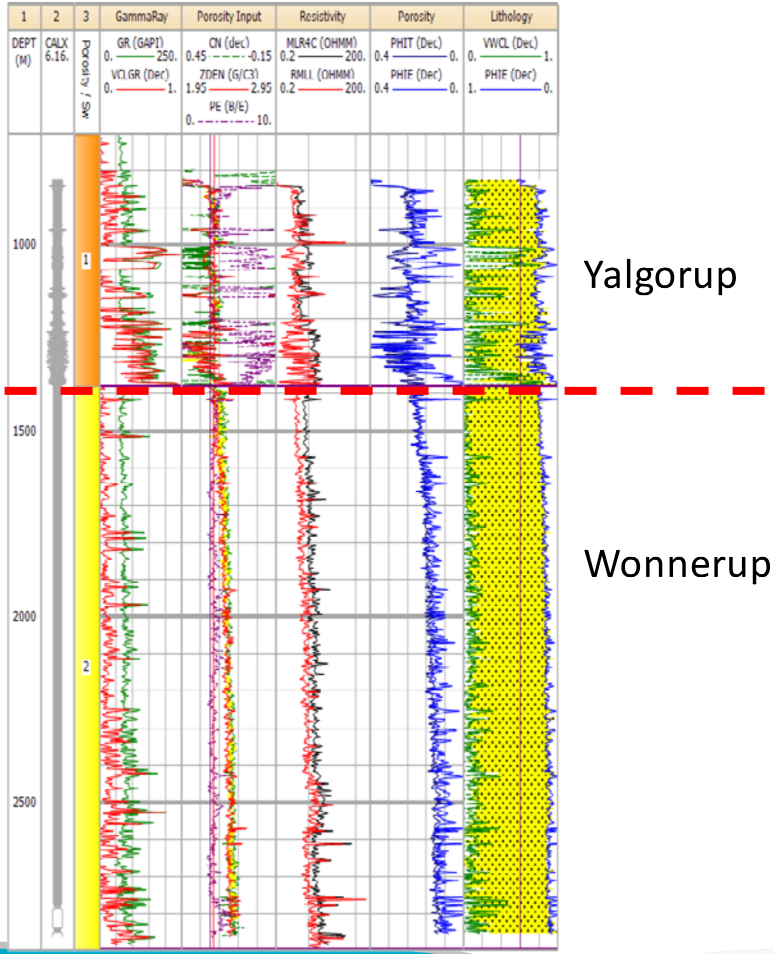
Samples


Quartz
K feldspar
Chlorite
Illite
Kaolinite
Al oxide
Mica
1 mm

Experimental conditions

Fluids:

- Reconstituted brine
- CO_2-saturated brine
- Vapour-saturated $scCO_2$



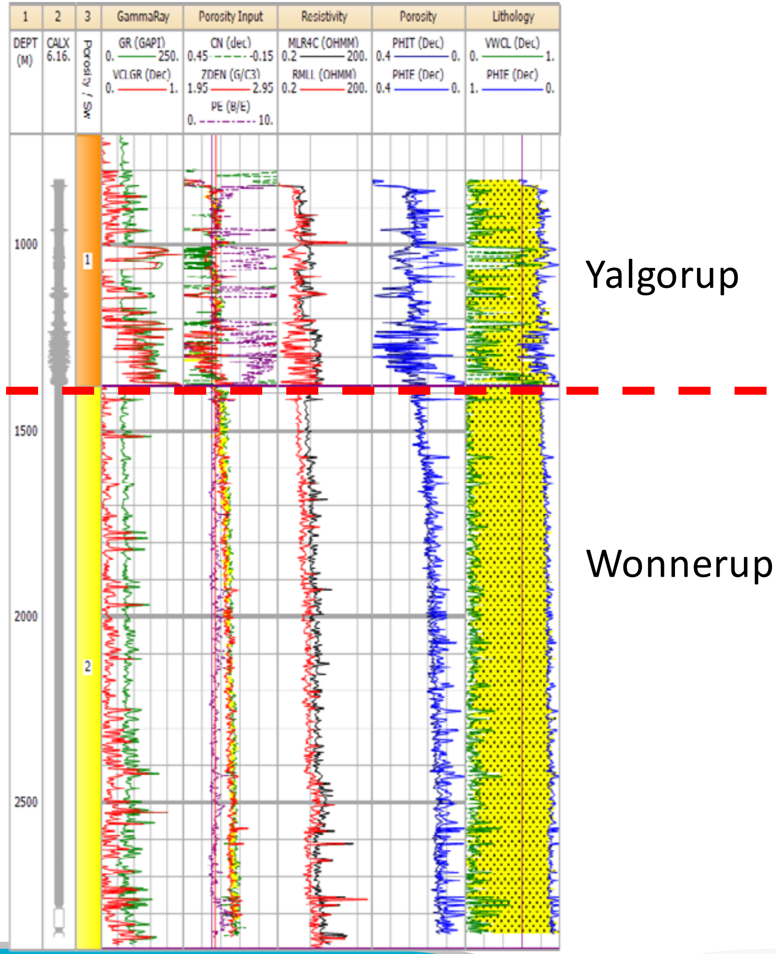
Experimental conditions

Fluids:

- Reconstituted
- CO_2-saturated brine
- Vapour-saturated $scCO_2$

P T and salinity:

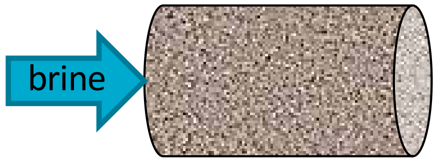
- Pore pressure & temperature estimated from surveys in Harvey-1
- Overburden pressure calculated from a pressure gradient of 25MPa/km (1PSI/ft)
- Salinity inverted from resistivity logs run in Harvey-1



Experimental procedure

Standard unsteady-state flooding procedure:

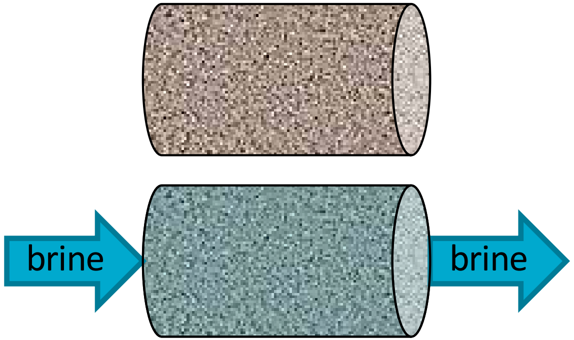
1. Vacuum sample for at least 15 hours
2. Brine saturation for at least 24 hours under in-situ conditions



Experimental procedure

Standard unsteady-state flooding procedure:

- Vacuum sample for at least 15 hours
- Brine saturation for at least 24 hours under in-situ conditions
- Multi-rate brine permeability measurement using CO_2-saturated brine under in-situ conditions



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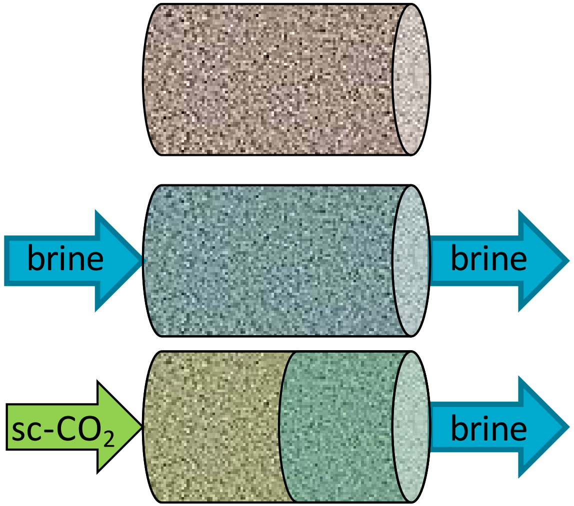
- Primary drainage flood: displace CO_2- saturated brine with vapour saturated scCO_2



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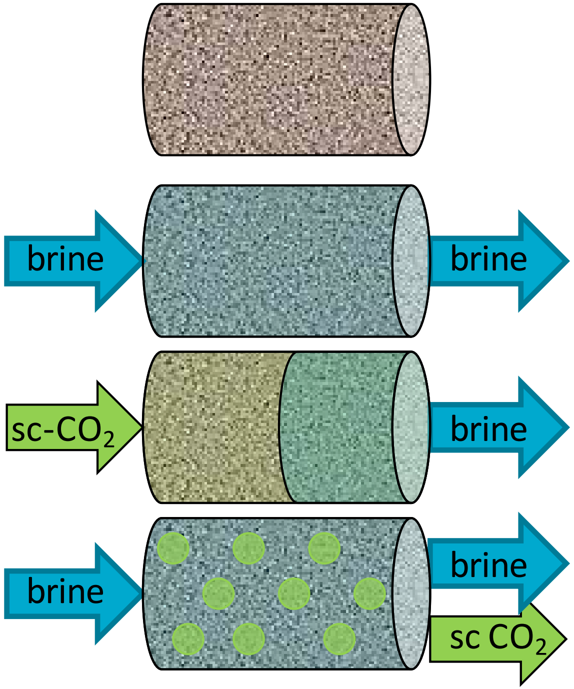
- Primary drainage flood: displace CO_2- saturated brine with vapour saturated scCO_2
- Primary imbibition: displace vapour-saturated scCO_2 with CO_2-saturated brine



Experimental procedure

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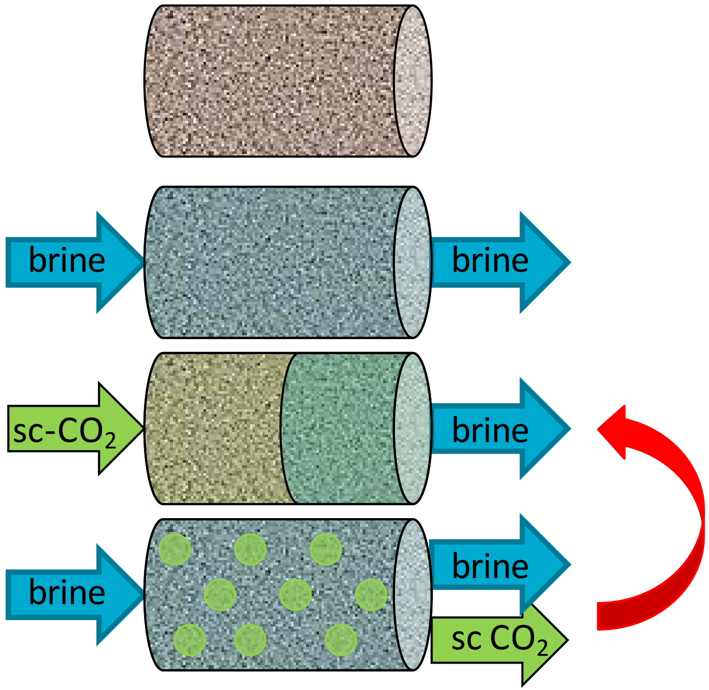
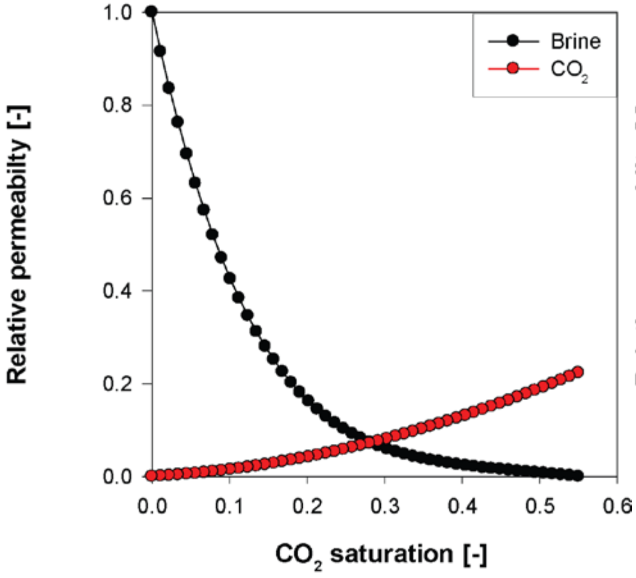
- Multi-rate brine permeability measurement using CO_2-saturated brine under in-situ conditions
- Primary drainage flood: displace CO_2- saturated brine with vapour saturated scCO_2
- Primary imbibition: displace vapour-saturated scCO_2 with CO_2-saturated brine
- Secondary drainage: for the 2nd time, displace CO_2-saturated brine with vapour-saturated scCO_2

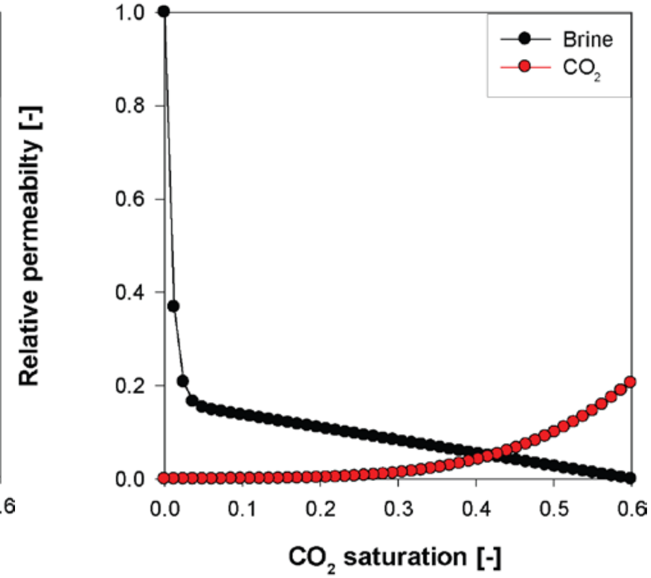


Results

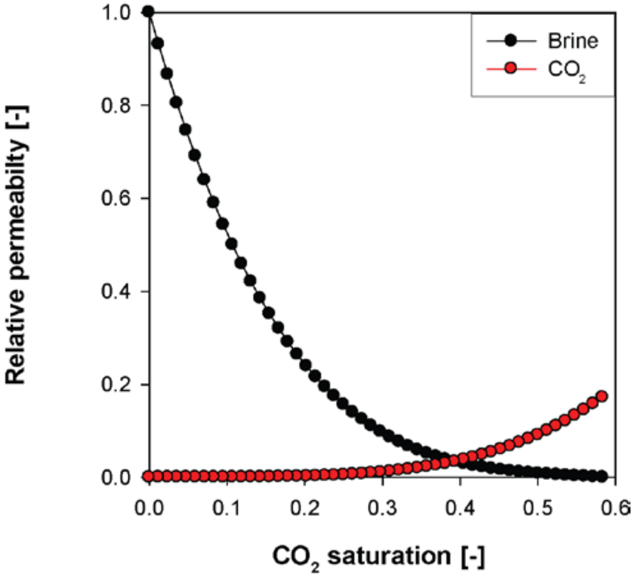
Results: relative permeability primary drainage flood



Depth, m	1,901.6
Pore pressure (MPa)	19.05
Overburden pressure (MPa)	43.02
Temperature (° C)	60.7

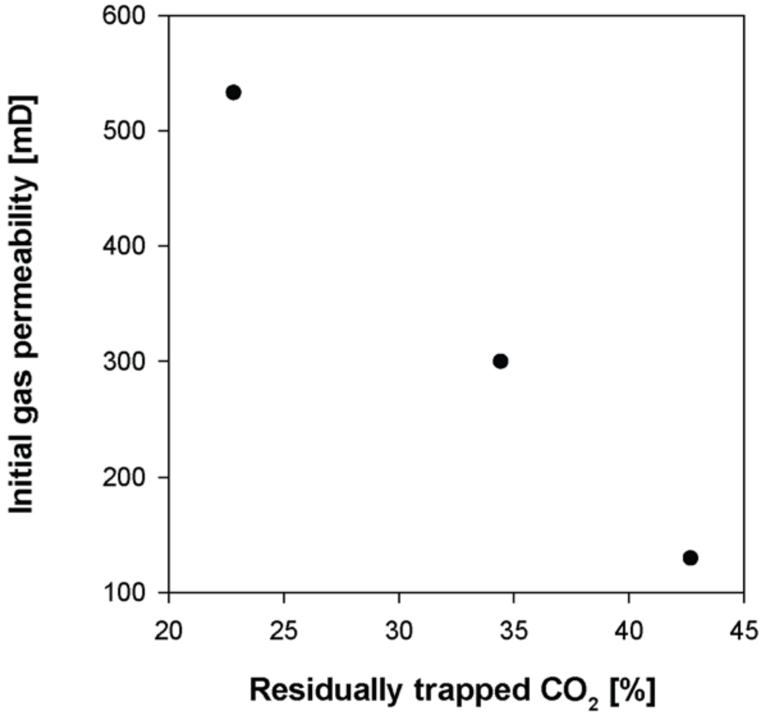


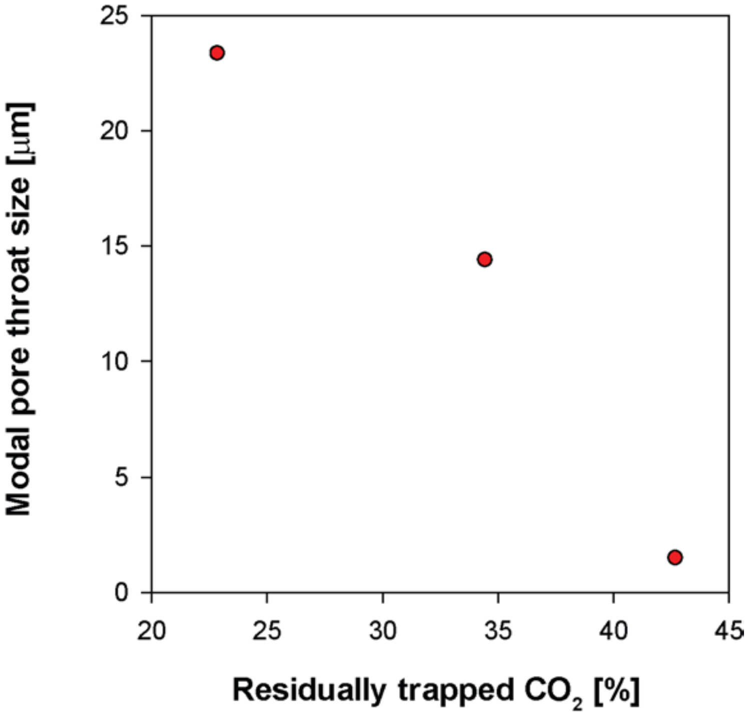
Depth, m	1,935.5
Pore pressure (MPa)	19.39
Overburden pressure (MPa)	43.78
Temperature (° C)	61.2



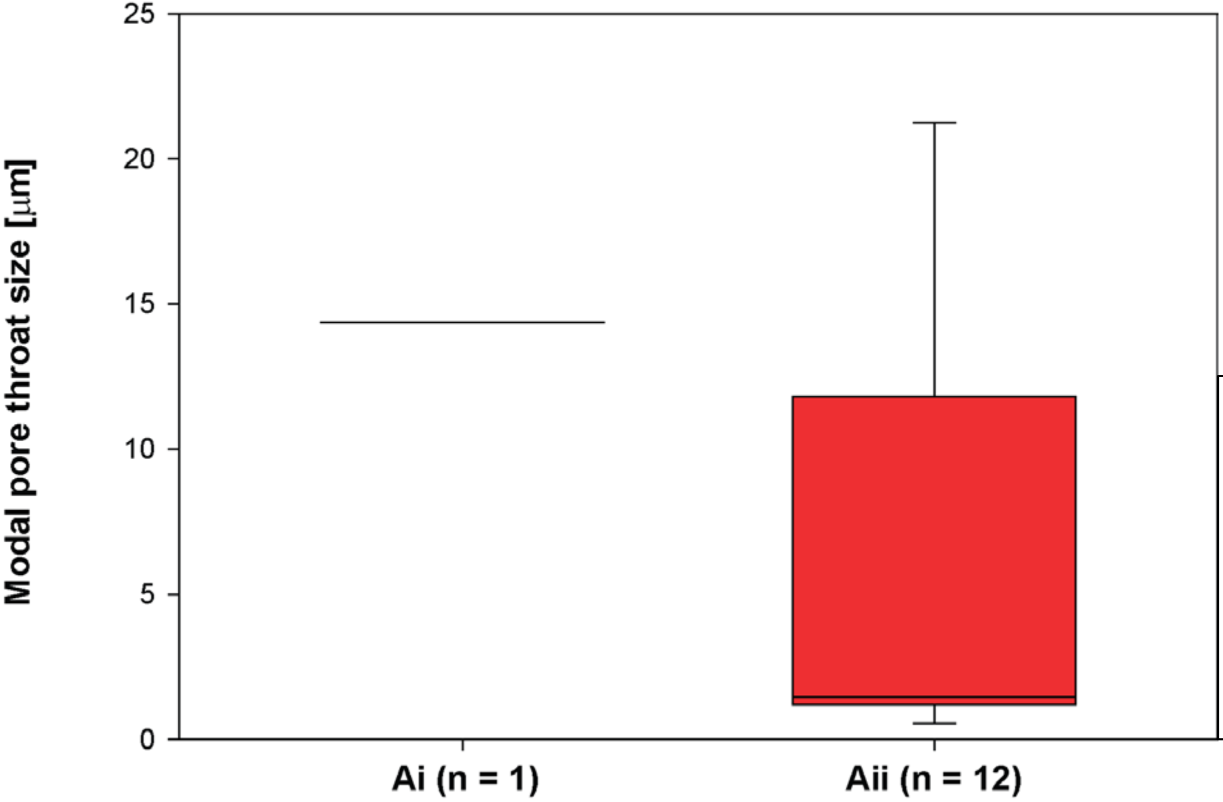
Depth, m	2,491.6
Pore pressure (MPa)	24.95
Overburden pressure (MPa)	56.36
Temperature (° C)	69.2

Results: residual saturation

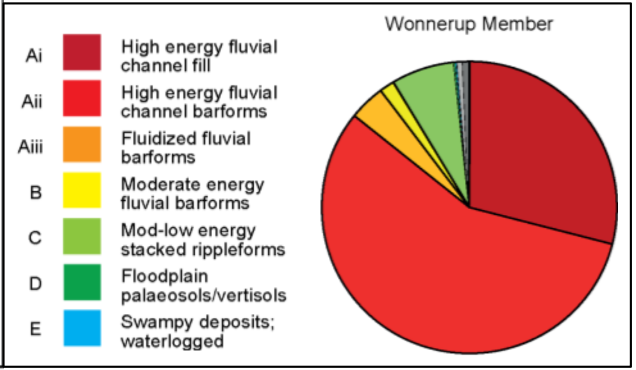




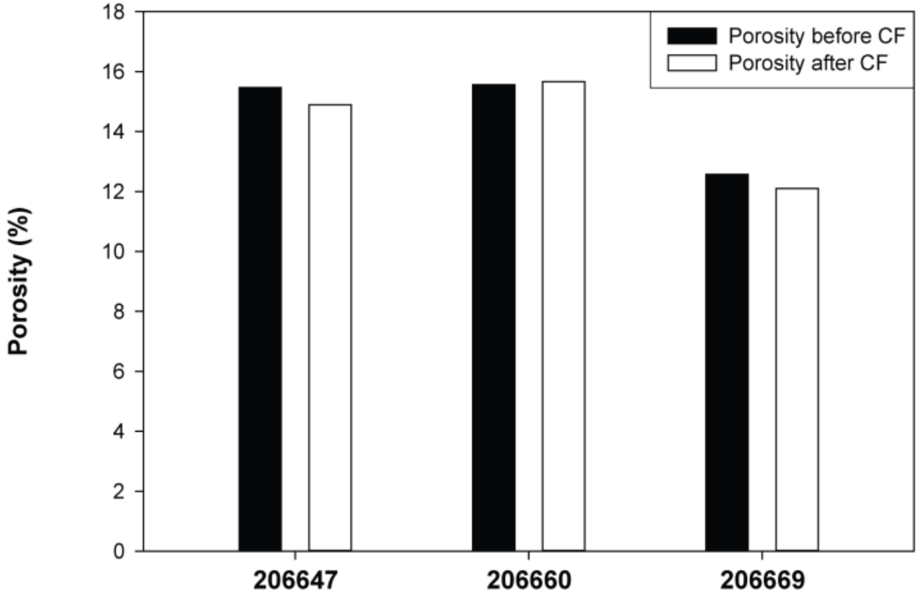
Results: residual saturation



Pore throat size range from MICP

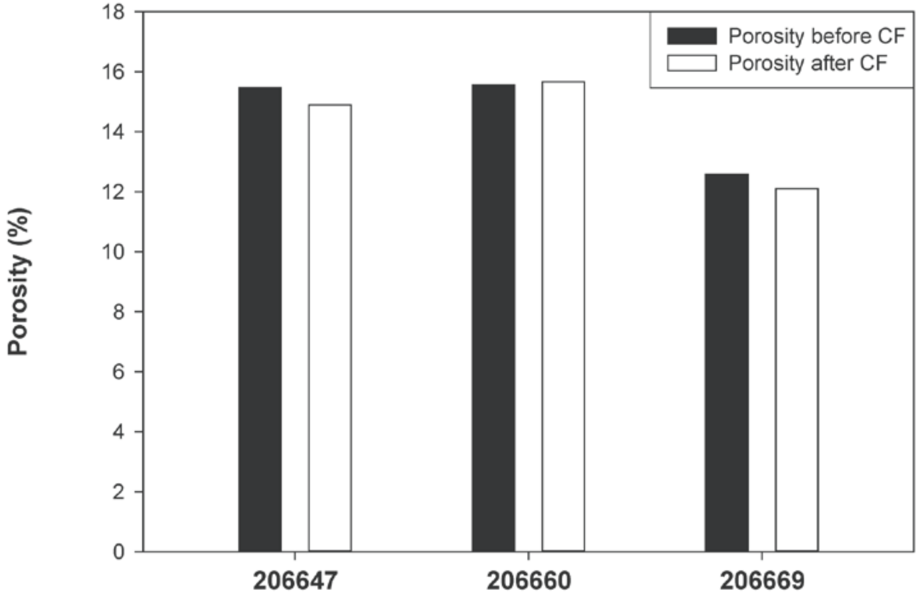


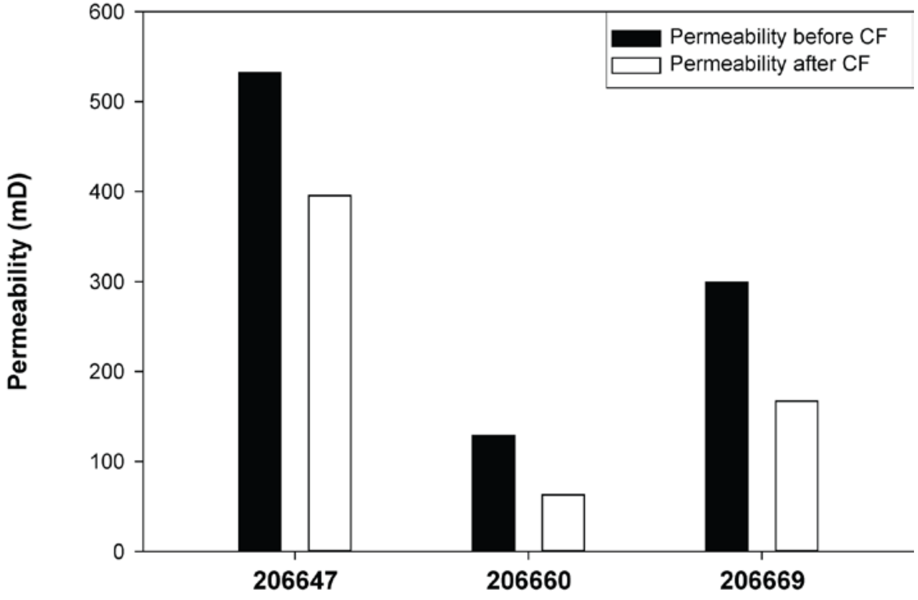
Results: Petrophysical changes



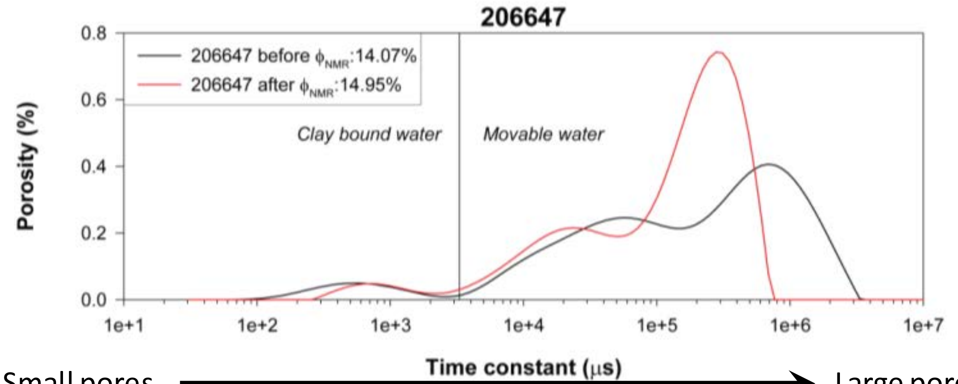
Results: Petrophysical changes

Porosity remained unchanged but <u>permeability decreased by 25%-51%</u>

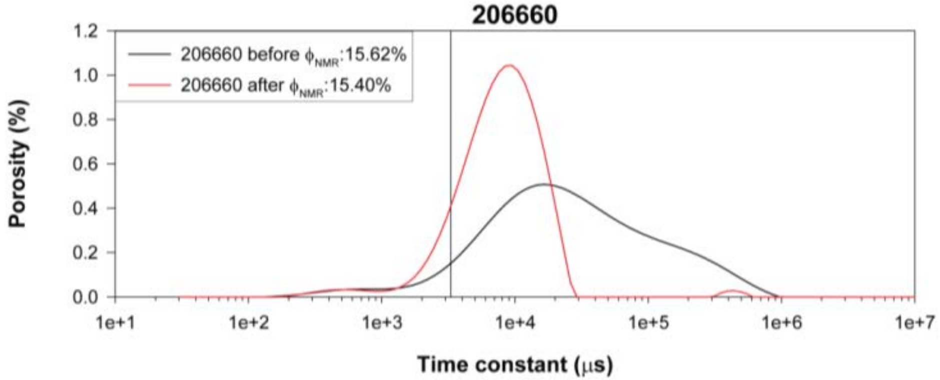




Results: Petrophysical changes



Small pores → Large pores

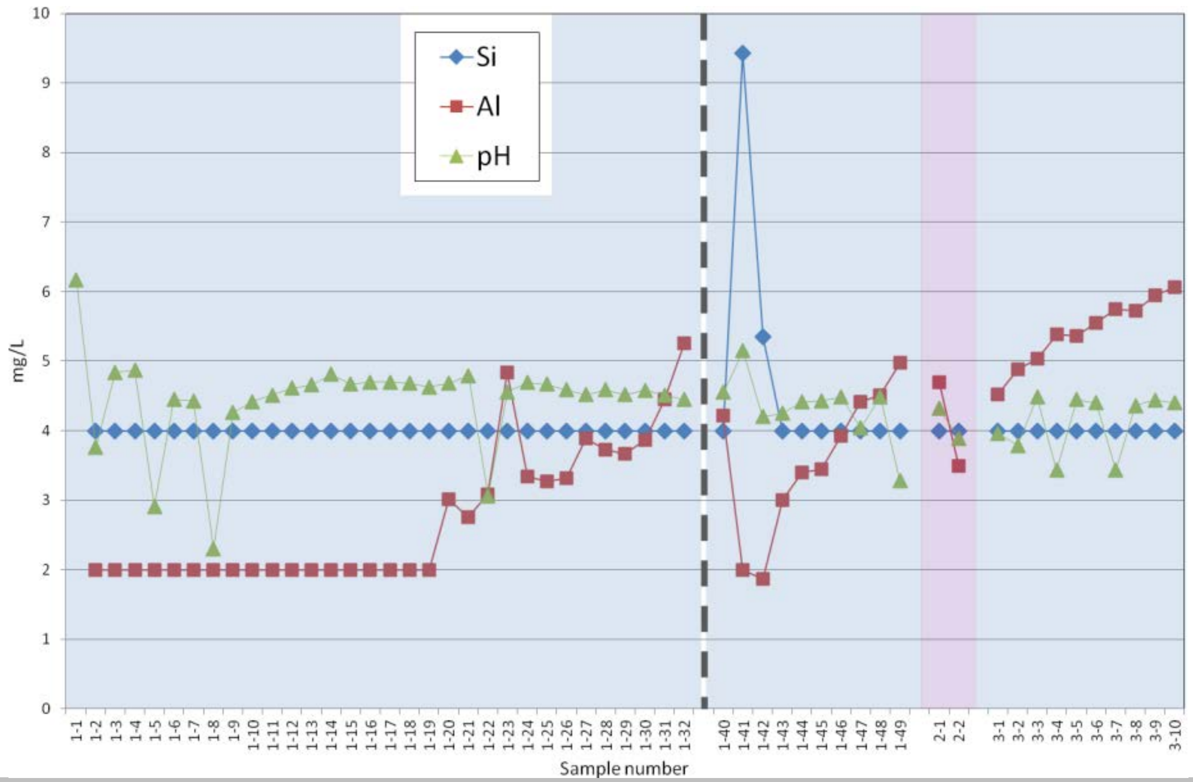


NMR T2 distributions in brine-saturated samples before and after core-flooding tests

Distribution shifted towards smaller pore sizes although the integrated total porosity is virtually unchanged

Small pores → Large pores

Discussion: fluid rock interaction

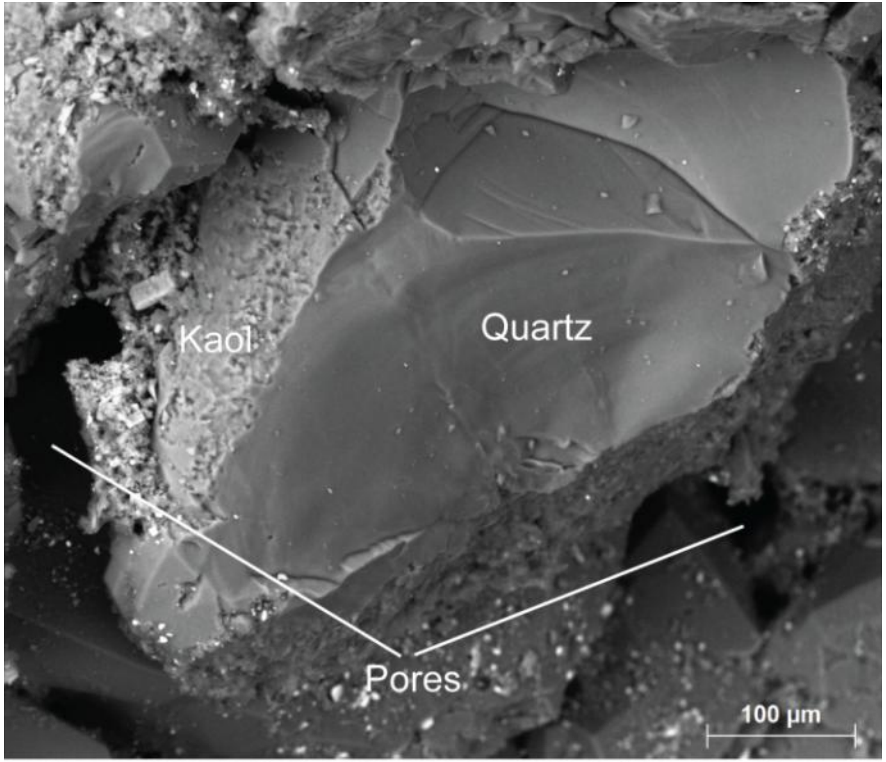


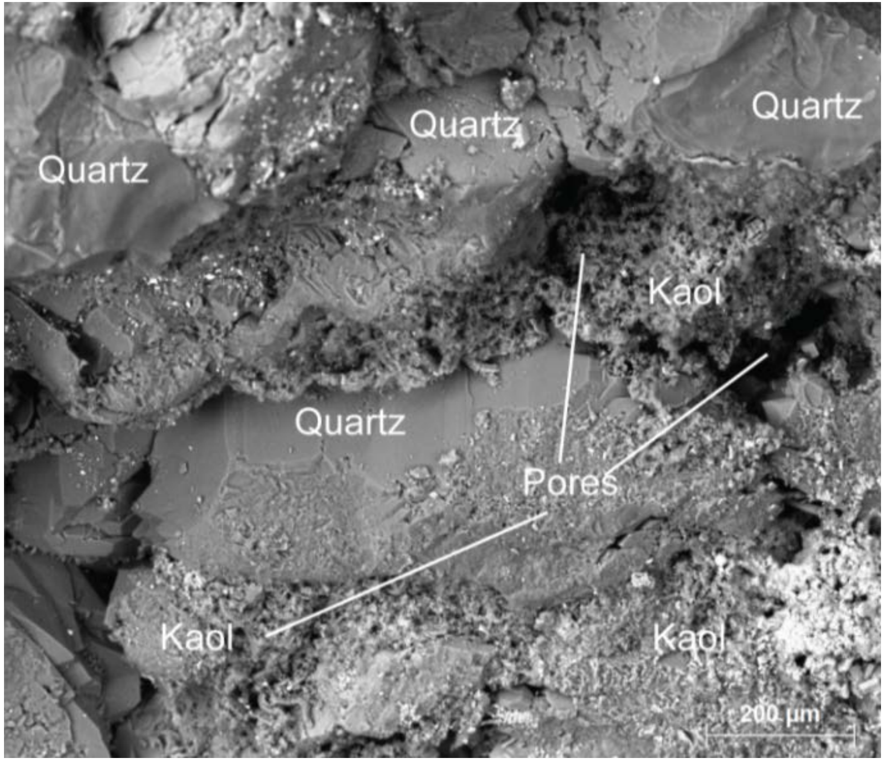
500-1000mL of fluids recovered

Possible dissolution of minerals;

Geochemical modelling supports precipitation of dawsonite: $NaAlCO_3(OH)_2$

Discussion: fines migration (?)





Conclusions

- Relative permeability and residual CO_2 saturation experimentally measured on 3 samples from the SW-Hub at in-situ conditions;

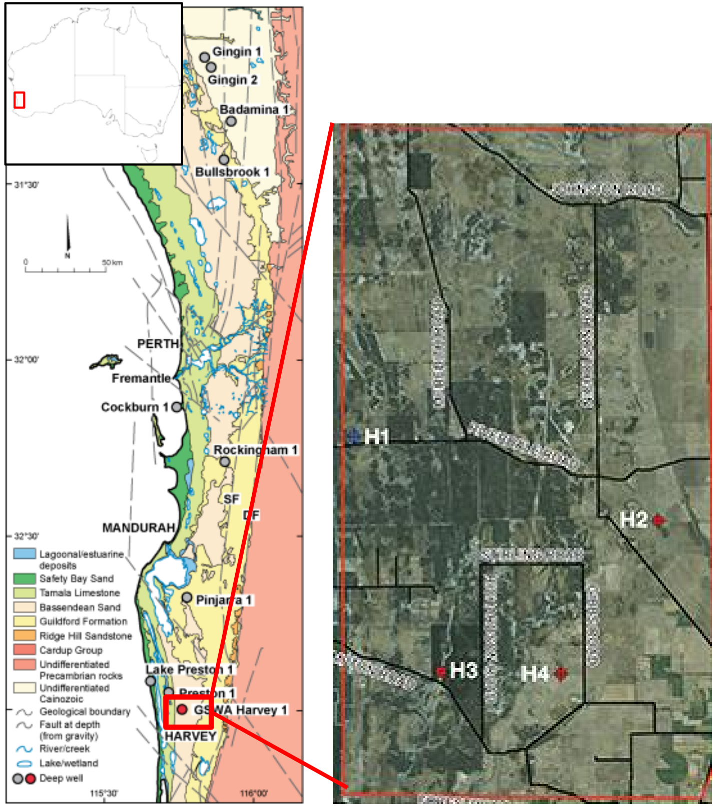
- Residual saturation were relatively high (23-43%), inversely proportional to the samples' permeabilities and modal pore throat size;

- Samples lost 25%-51% of their original permeability as a results of the fluid-rock interactions during core-flooding tests;

- Pore-size distribution inferred from NMR indicates a shift towards smaller pore size although the total porosity remains the same;

- Effluent and geochemical analysis support the precipitation of dawsonite and mobilization of fines (kaolinite) as possible mechanisms to explain the observed degradation of permeability

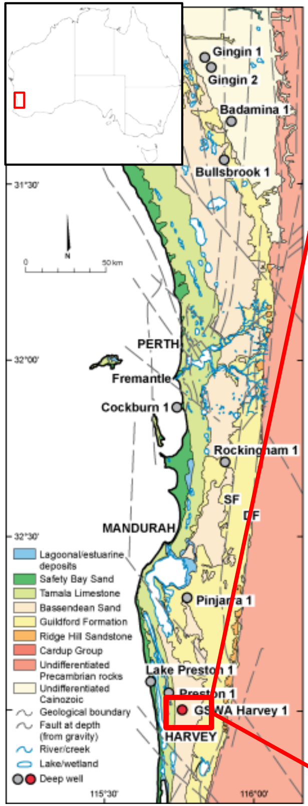
Outlook



3 more wells drilled in in the SW-Hub to test:

- Injectivity potential in the Wonnerup;
- Containment potential in the Yalgorup

Outlook



3 more wells drilled in in the SW-Hub to test:

- Injectivity potential in the Wonnerup;
- Containment potential in the Yalgorup

Ongoing research focused on fluid-rock interactions:

- Systematic sampling of fluids during core flooding;
- Systematic assessment of mineralogy variations;
- In-situ visualization using X-ray μCT;
- Focus on in-situ brine salinity

Acknowledgements

anlecr&d

Government of Western Australia
Department of Mines and Petroleum

Australian Government
Department of Industry and Science

Thanks

Experimental data:

Delle Piane C, Olierook HKH, Timms NE, Saeedi A, Esteban L, Rezaee R, Mikhaltsevitch V, Iglauer S, Lebedev, M. Facies-baed rock properties distribution along the Harvey 1 stratigraphic well. Report to ANLEC R&D 7-1111-0199; 2013. www.anlecrd.com.au/.

Geochemical data:

Stalker L, Noble R, Gray D, Trefry C, Varma S, Ross A, Sestak S, Armand S, Gong S. Geochemical characterisation of gases, fluids and rocks in the Harvey-1 data well. Report to ANLEC R&D 7-1111-0200; 2013. http://www.anlecrd.com.au/

Geological core description, mineralogy and diagenesis:

Olierook, H. K., Delle Piane, C., Timms, N. E., Esteban, L., Rezaee, R., Mory, A. J., & Hancock, L. (2014). Facies-based rock properties characterization for CO 2 sequestration: GSWA Harvey 1 well, Western Australia. *Marine and Petroleum Geology*, *50*, 83-102.

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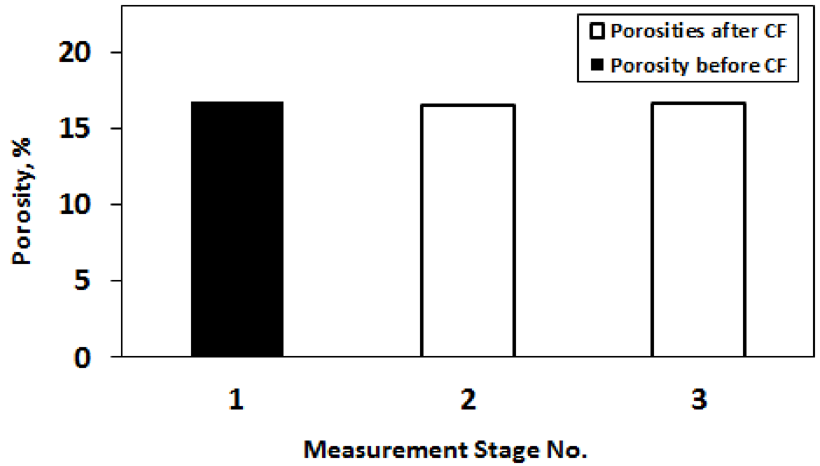
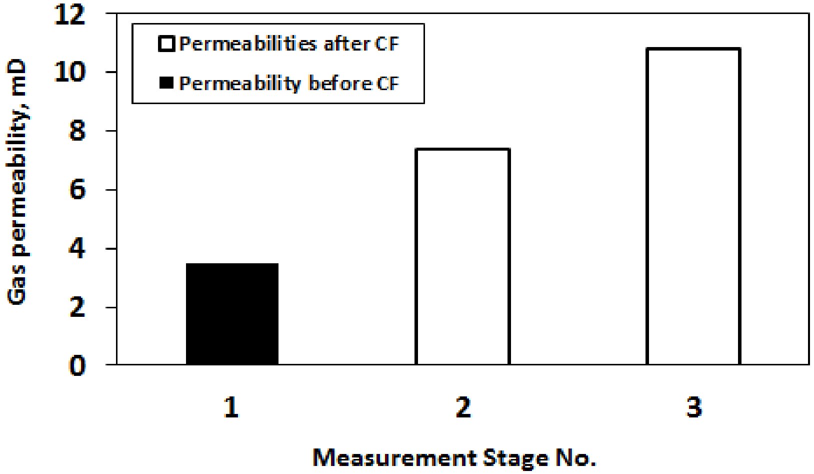
Results

- Change in porosity and permeability of a different sample from Lesueur Formation taken from Pinjarra-1 after undergoing the flooding procedure:





- Porosity remained unchanged but permeability increased by more than 300%.