Pore System Changes During Experimental Polymer Flooding in Ben Nevis Formation Sandstones, Hebron Field, Offshore Eastern Canada*

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Abstract

Experimental polymer flooding was conducted in Ben Nevis (BN) Formation sandstones from Pool 1, Hebron Field, first heavy oil field offshore Eastern Canada and the effects are investigated as part of an ongoing study aimed at identifying polymers that can be applied to this field. The study focuses on the potential of this enhanced oil recovery (EOR) method on sandstones with interconnected pore networks and relatively low permeability (200 – 600 mD). Polymer floods consisted of selected partially hydrolyzed polyacrylamide and the biopolymer Guar Gum. The mineralogy and texture of the sandstones were studied before and after the injection by both optical microscopy and scanning electron microscopy and mineral liberation analysis (SEM-MLA), and quantification was completed using digital image analysis. The studied cores were sampled from the exploration wells in Pool 1, Hebron Field and mainly consist of fine to very fine grained sublitharenites with similar mineralogy but different textures (homogeneous vs. heterogeneous). The results obtained from the flooded core sandstone samples indicate a porosity increase and a qualitative permeability rise. Intergranular clay matrix detachment and partial removal from the rock sample (due to polymer flooding input/release drag) are the main processes that explain the porosity increase. Carbonate cements were relatively stable and no substantial changes were observed. Additional textural changes observed were minor and consisted of variations in the roughness of grain-pore contacts, pore shape and aspect ratio. Primary texture of the rock subjected to polymer flooding injection is an important factor and seems to enhance textural/mineralogical changes in heterogeneous systems. These results simulate the polymer flooding injection nearest to the production well and indicate that, in this environment, where the polymer flood pushes out the oil and brine fluids and interacts with rocks, some mineralogical/texture

re-adjustments take place. Possible porosity and permeability increases could facilitate the polymer flooding but textural re-adjustment could also affect the rock physical properties; thus affecting the oil recovery.

References Cited

Maia, A.M.S., R. Borsali, and R.C. Balaban, 2009, Comparison between a Polyacrylamide and a Hydrophobically Modified Polyacrylamide Flood in a Sandstone Core: Materials Science and Engineering, C29, p. 505-509.

Normore, L.S., 2006, Origin, distribution, and paragenetic sequence of carbonate cements in the Ben Nevis Formation, White Rose Field, Jeanne d’Arc Basin, offshore Newfoundland, Canada: Memorial University of Newfoundland, M.Sc. Thesis, 216 p.

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Memorial University of Newfoundland

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Pore System Changes at Hebron Field:

Outline

• **Hebron Project Overview**	**2 min**
• **Enhanced Oil Recovery**	**2 min**
• **Experimental Methodology**	**4 min**
– Coreflooding Experiments	
– Mineral Analysis Techniques	
• **Results**	**5 min**
• **Conclusions**	**2 min**

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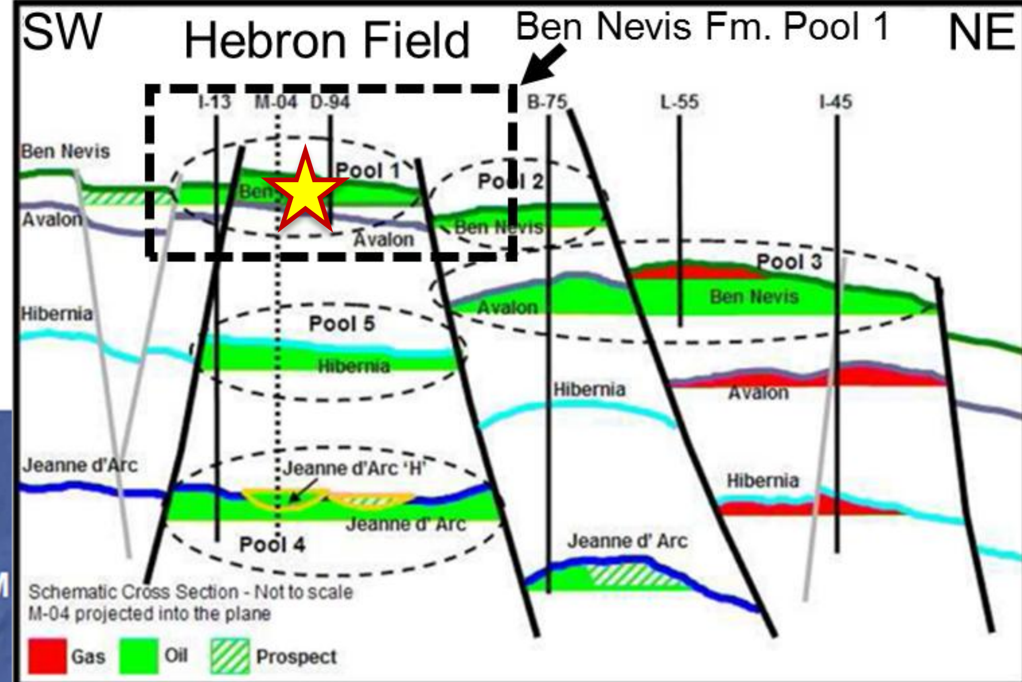
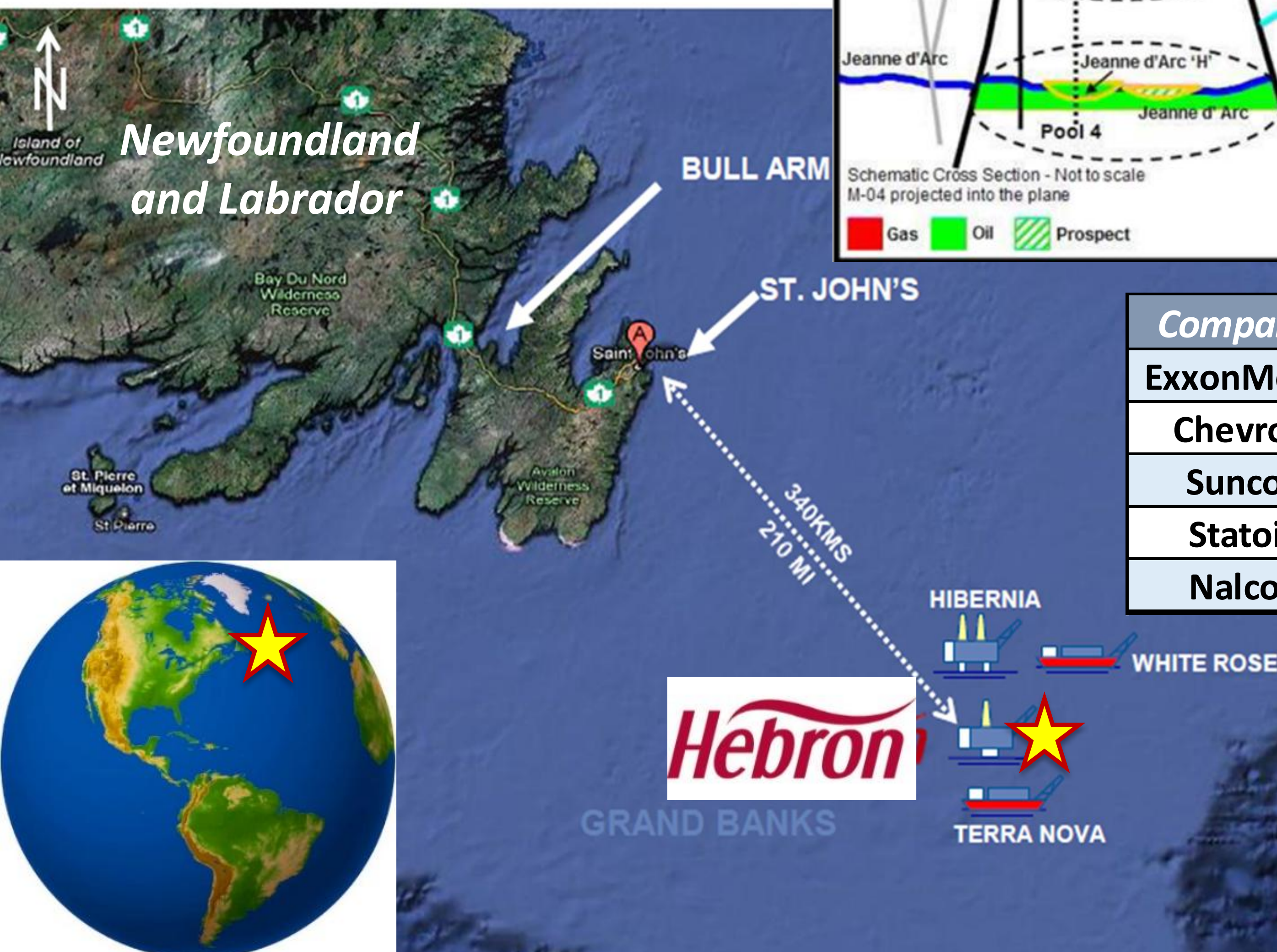
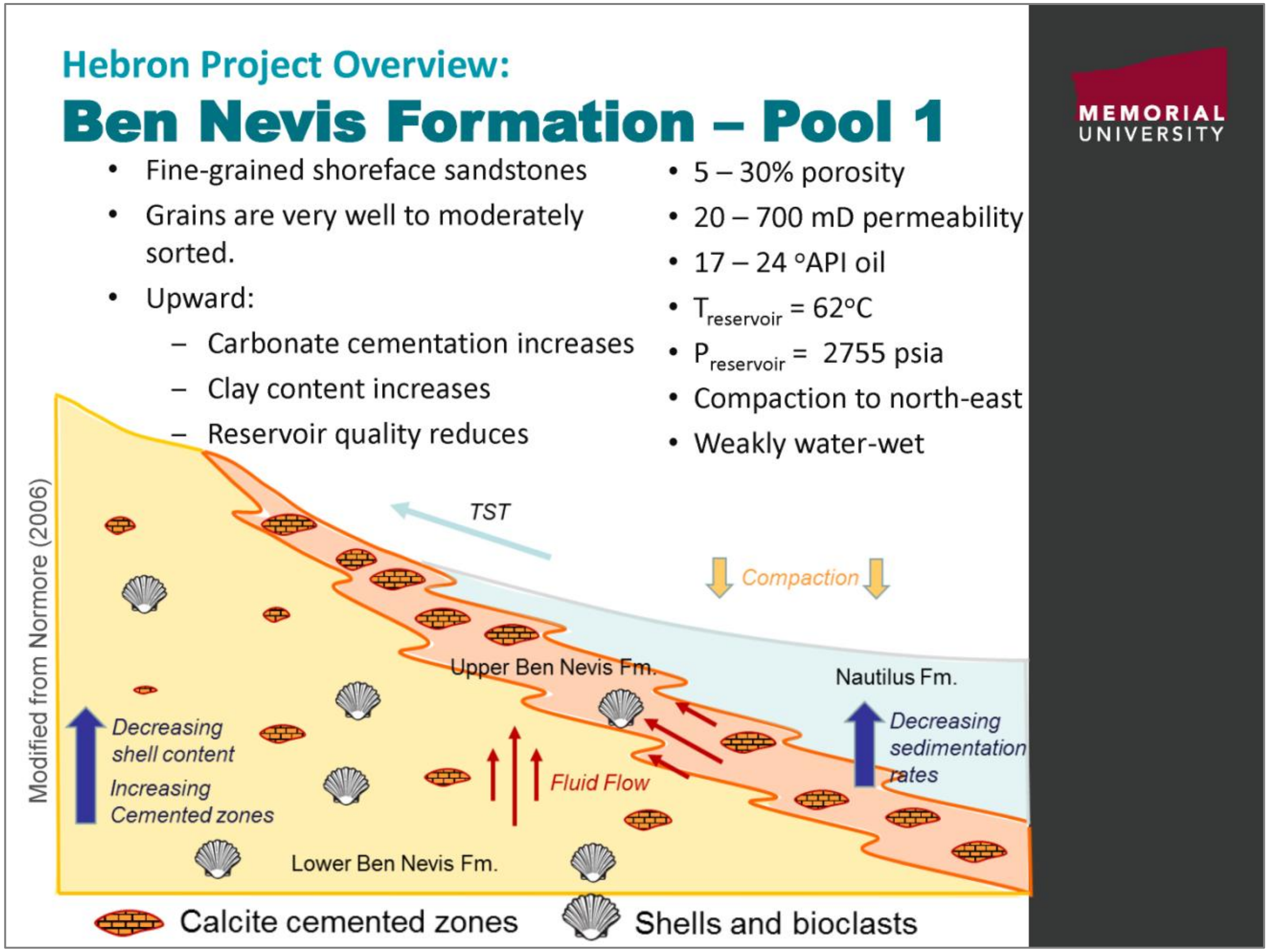
Hebron Project Overview:

Location





Company	Working Interest (%)
ExxonMobil	36.0
Chevron	26.6
Suncor	22.7
Statoil	9.7
Nalcor	4.9



Presenter's notes:

- Grains are very well to moderately well sorted, with little evidence of size-sorting trends.
- Going up through the reservoir:
    - Increase calcium carbonate cementation events
    - Clay contents increase due to potentially the depositional setting or bioturbation
    - Reservoir quality reduction

Enhanced Oil Recovery:

Stages of Oil Recovery

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Primary	Secondary	Enhanced Oil Recovery
Pressure Drawdown	Water flood Gas Injection	**Chemical** surfactants, polymer, caustic, foam **Gas** CO_2, miscible solvent, inert gas **Thermal** Steam, hot water, in-situ combustion **Other** microbial, gravity drainage, .

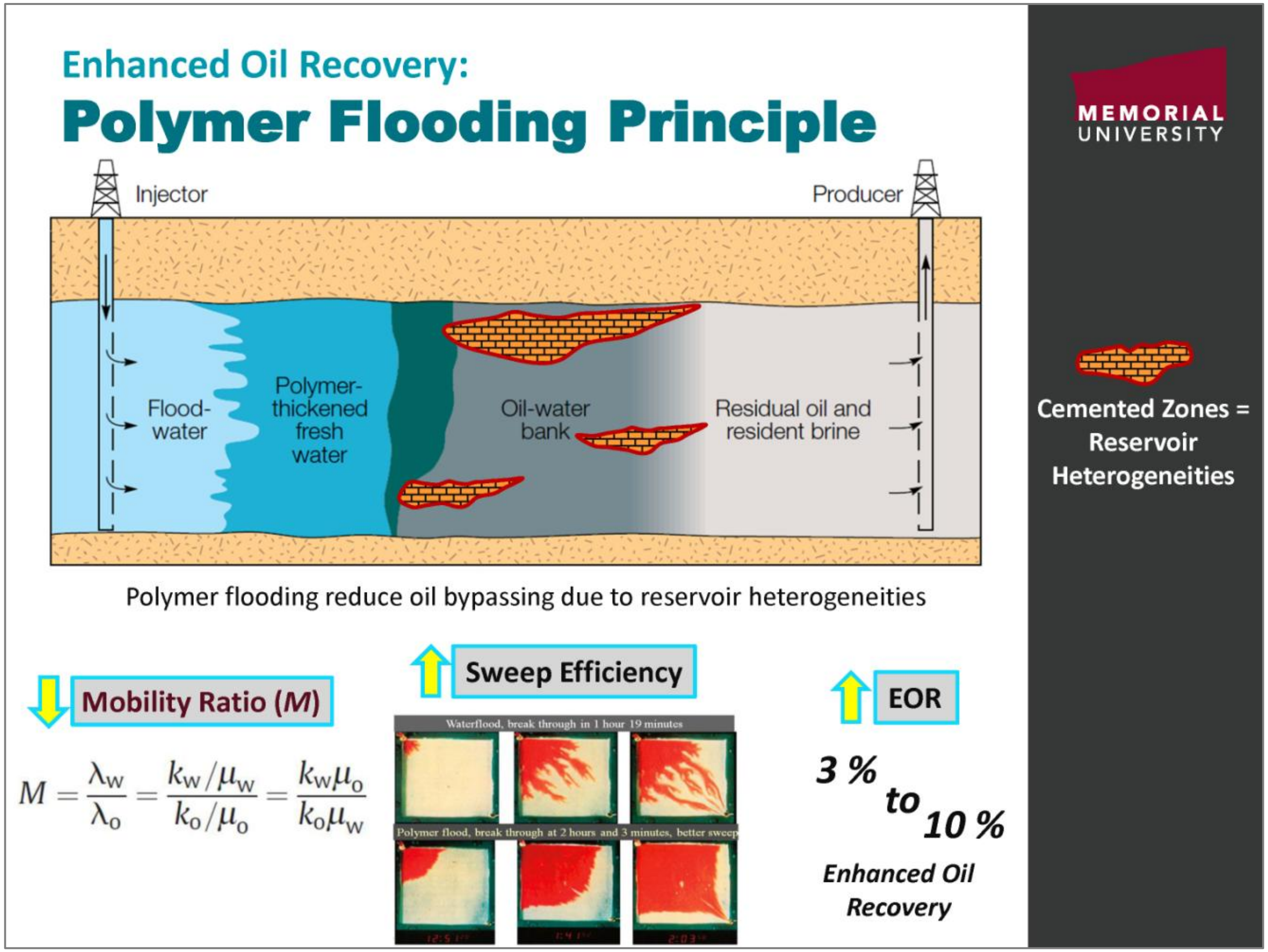
Improved Oil Recovery

EOR targets immobile oil

- fluid-fluid interactions
  - Mobility ratio
  - Interfacial tension
- Fluid-rock interactions
  - Contact angle

IOR targets mobile & immobile oil

- Physical: directional wells, well stimulation
- Procedural: advanced completions
- Mechanical: artificial lift (gas lift, reciprocating cavity pumps, ESPs)



Presenter's notes:

- Polymers are added in water to increase the viscosity of the injected fluid (water) in order to improve the mobility ratio between oil and displacing fluid, and thus improve the volumetric reservoir sweep efficiency (Maia et al. 2009)
- Develop a more uniform volumetric sweep of the reservoir
- Reduce oil bypassing due to reservoir heterogeneities
- Limit unwanted physical phenomena such as viscous fingering

Experimental Methodology

Workflow

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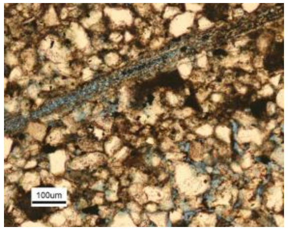
Before Flooding

6 inches

Coreflooding Experiments

After Flooding

6 inches

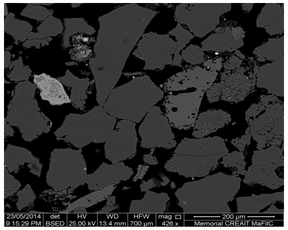


Optical Microscopy

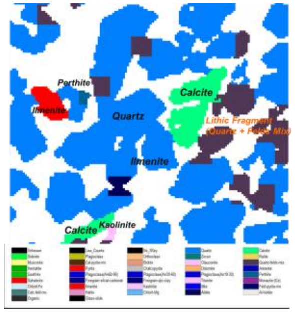
Reservoir Characterization

Digital Image Analysis (DIA)

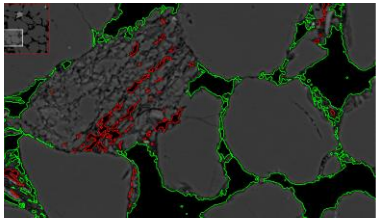
Scanning Electron Microscopy (SEM)



Mineral Liberation Analysis (MLA)



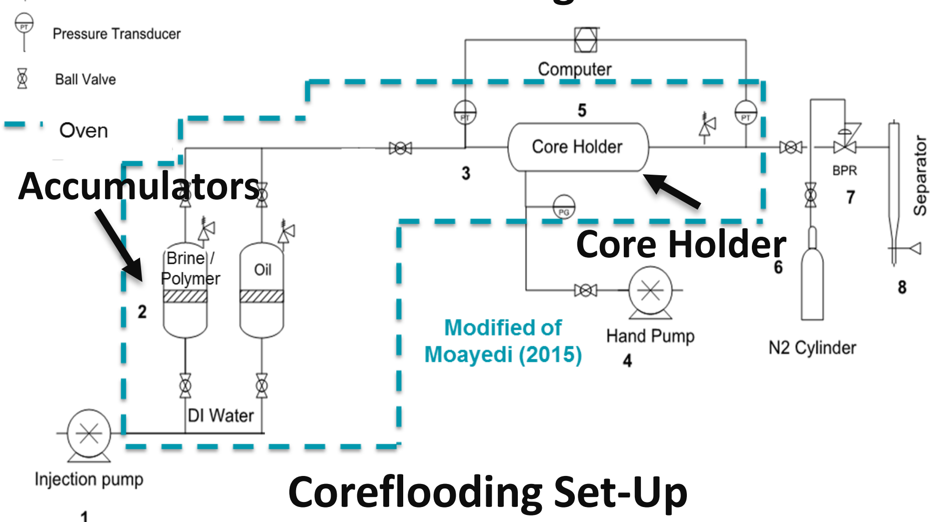
Pore Geometry Definition



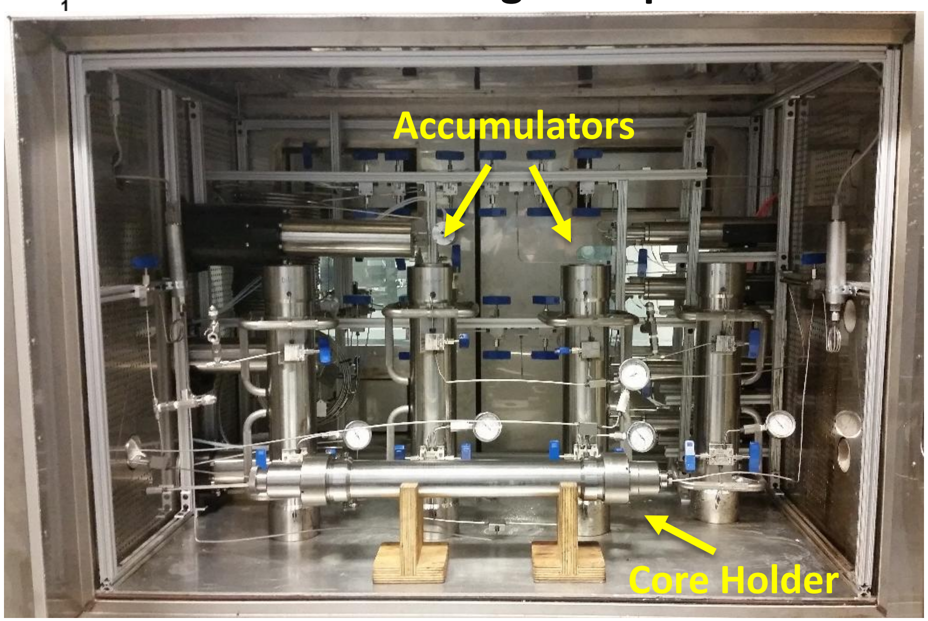
Experimental Methodology

Coreflooding Experiments

Coreflooding P&ID



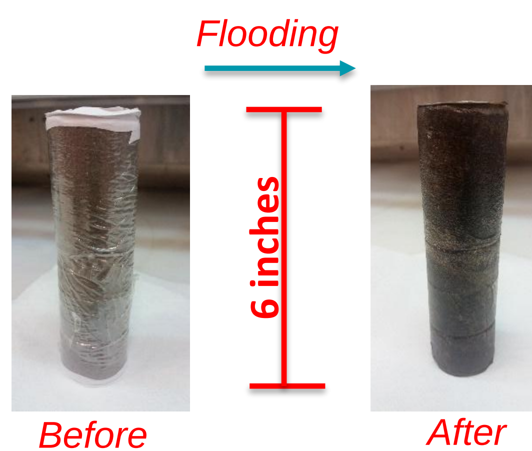
Coreflooding Set-Up



Reservoir Experimental Conditions

- Temperature: ***62° Celsius***
- Back Pressure: ***2800 psi***
- Overburden Pressure: ***3500 psi***

Cores State

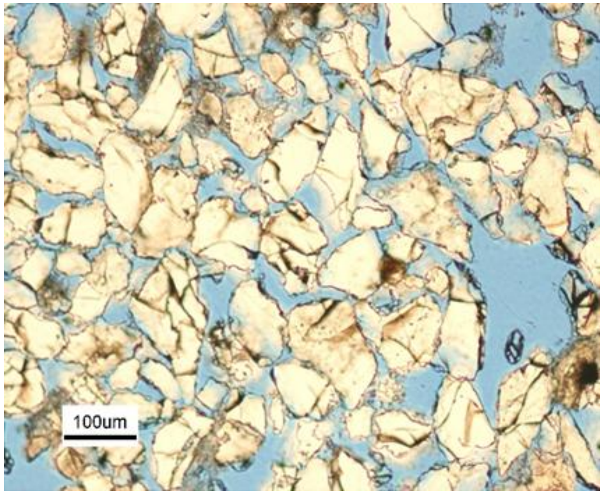


Experimental Methodology

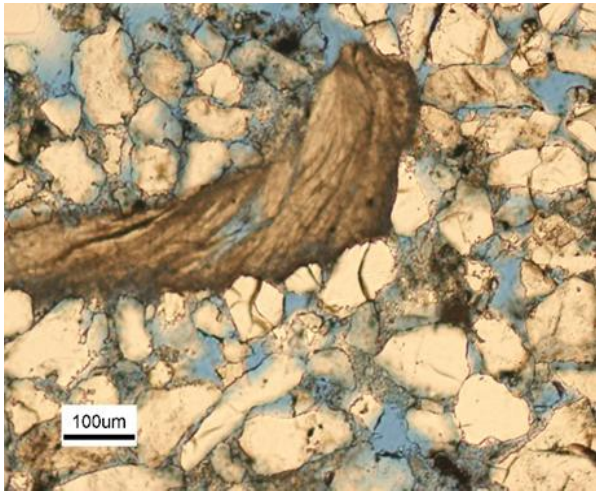
Mineral Analysis Techniques

Optical Microscopy

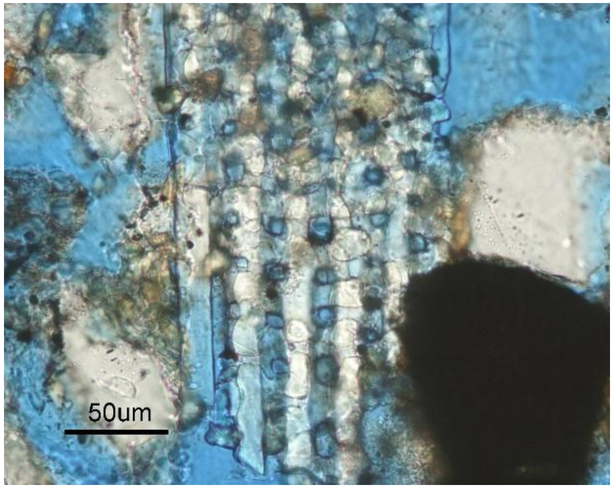
OF-6 (M-04) Quartz fractures



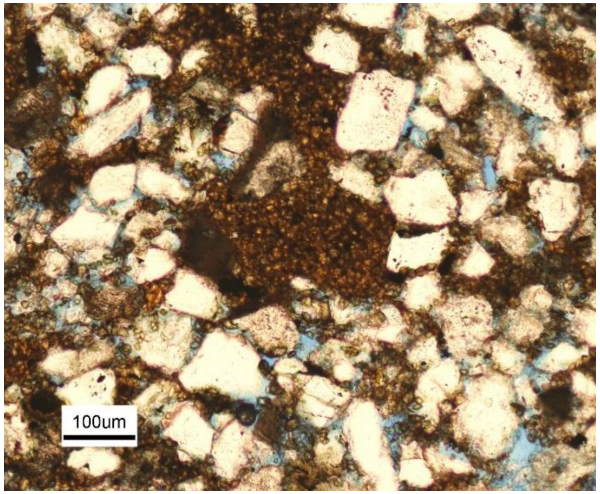
OF-03 (M-04) Bioclast



OF-14 (D-94) Feldspar dissolution



OF-14 (D-94) Siderite Cement



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Experimental Methodology

Mineral Analysis Techniques

SEM & MLA

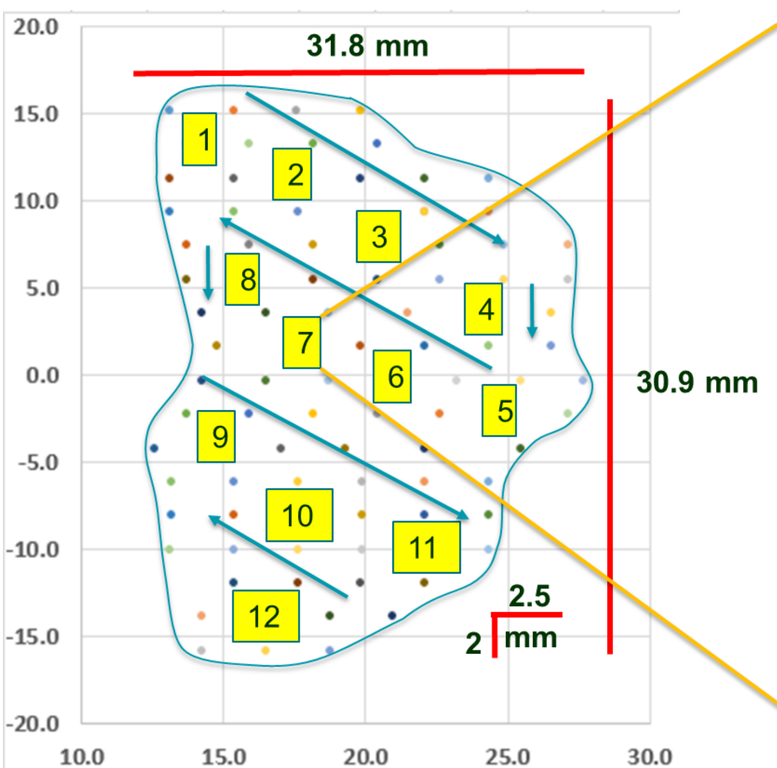
Experiment Definition

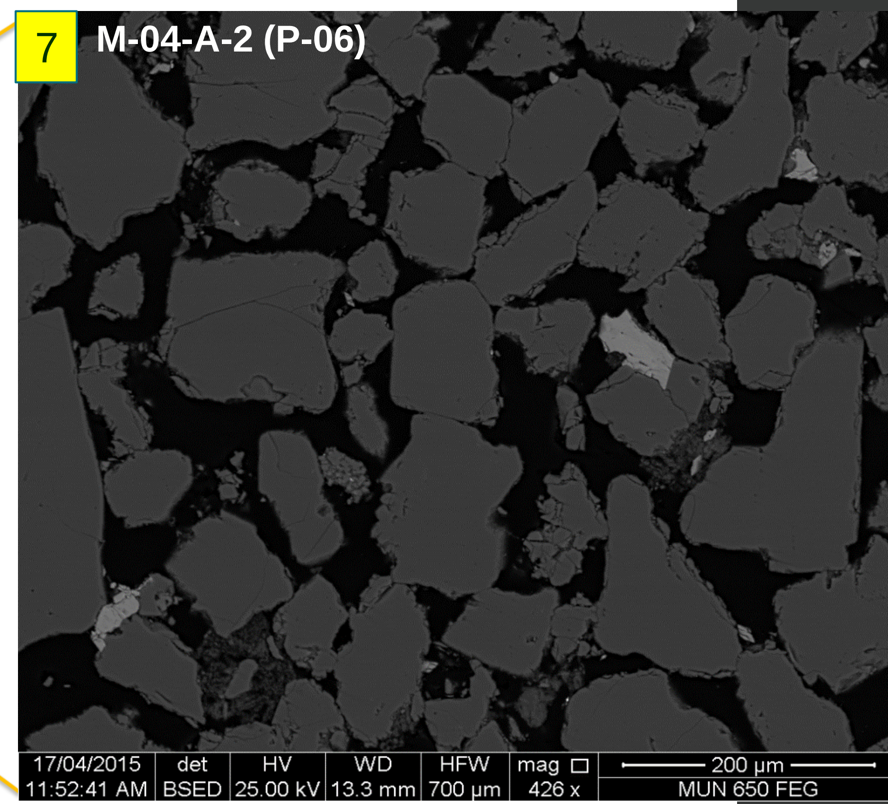
Independent Variables			Dependent Variable
Permeability Facies	**Sorting**	**Polymer Flood Timing**	**Porosity**
Low (50-120)	**Heterogeneous**	**Tertiary**	
High (1340-1400)	**Homogeneous**	**Secondary**	

Plackett-Burman Experiment Design

Experiments #: 8

Image Selection



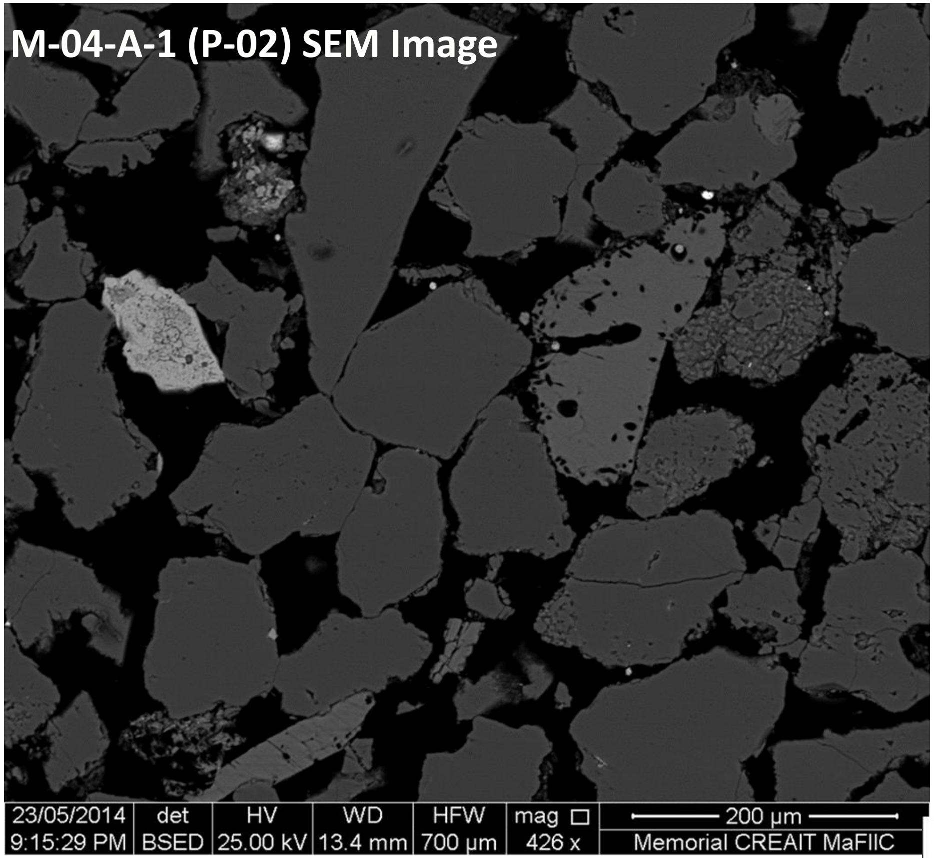


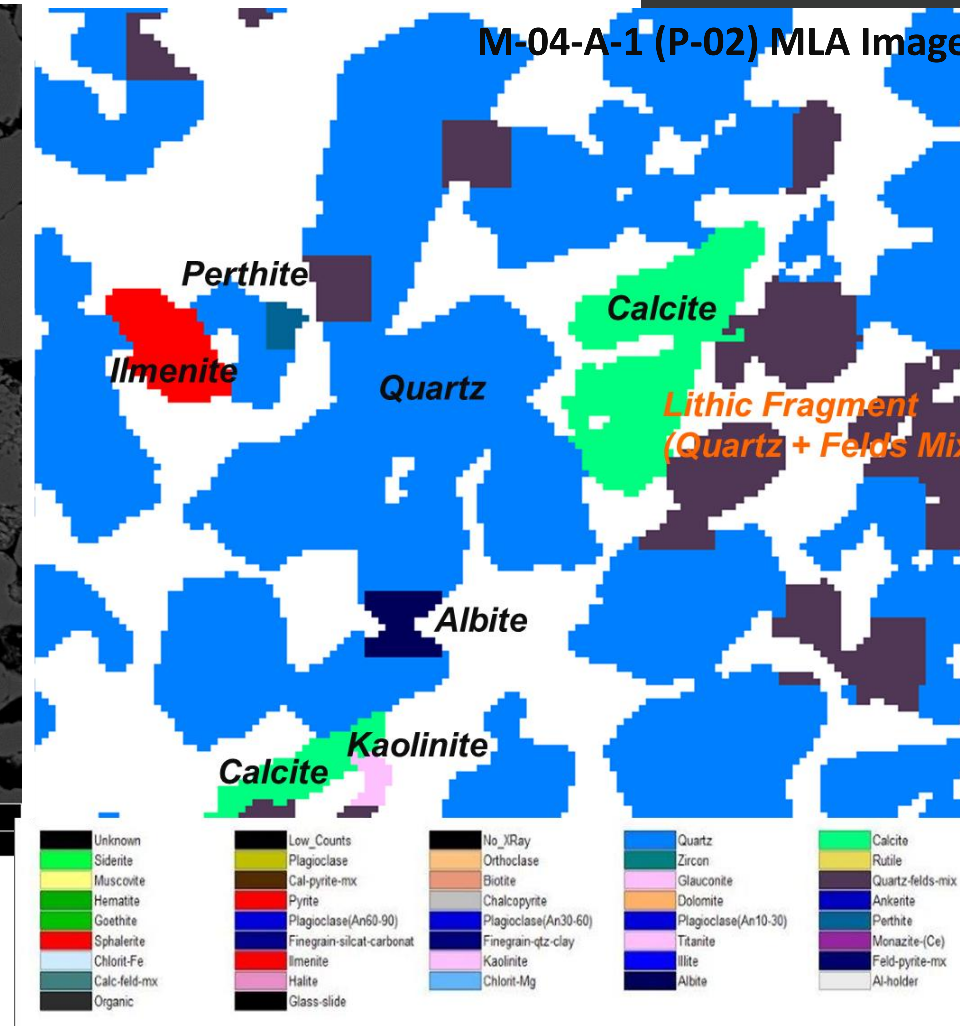
Experimental Methodology

Mineral Analysis Techniques

SEM & MLA

Porosity Estimation and Pore System Definition



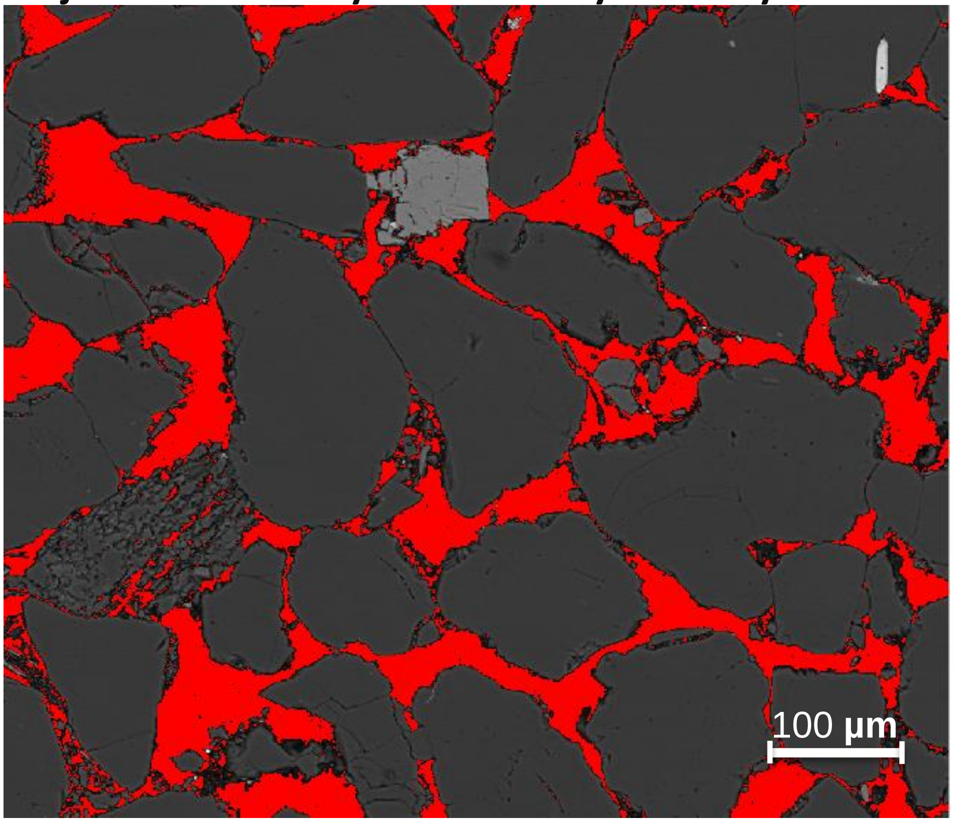


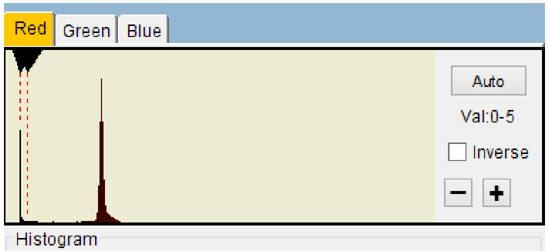
Experimental Methodology

Mineral Analysis Techniques

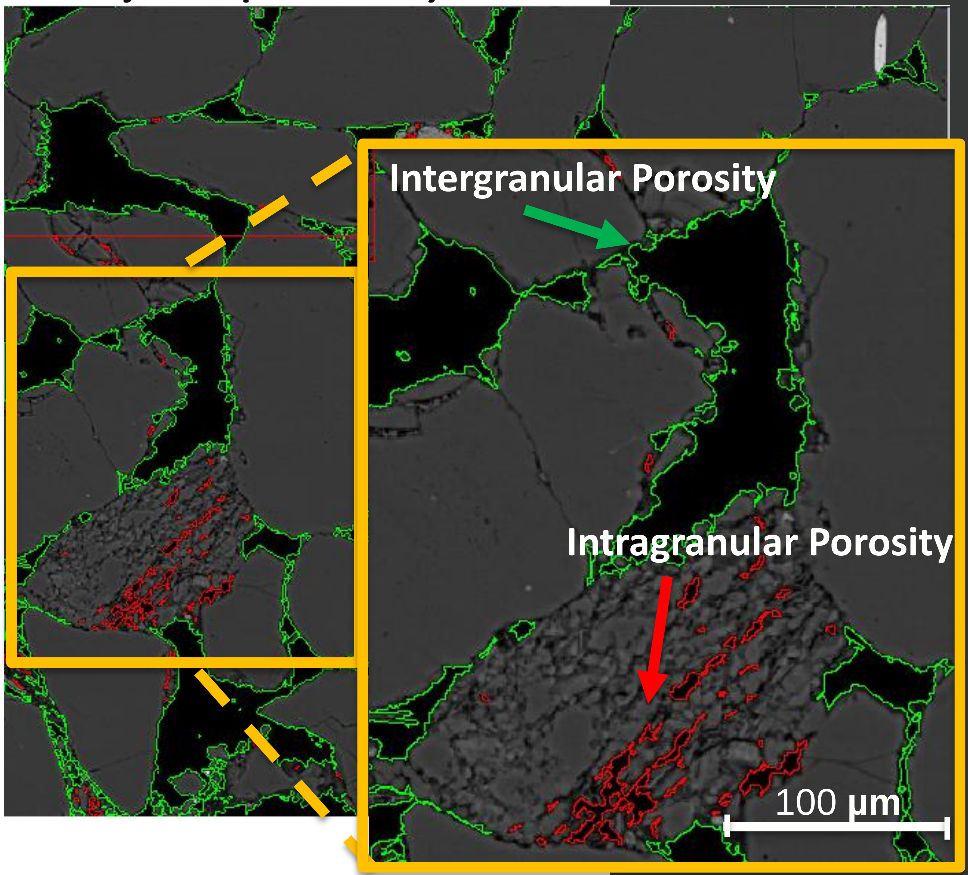
DIA using JMicroVision v1.27

Object Extraction by Color or Gray Intensity Threshold





Object Separation by Classes



Results

Reservoir Characterization

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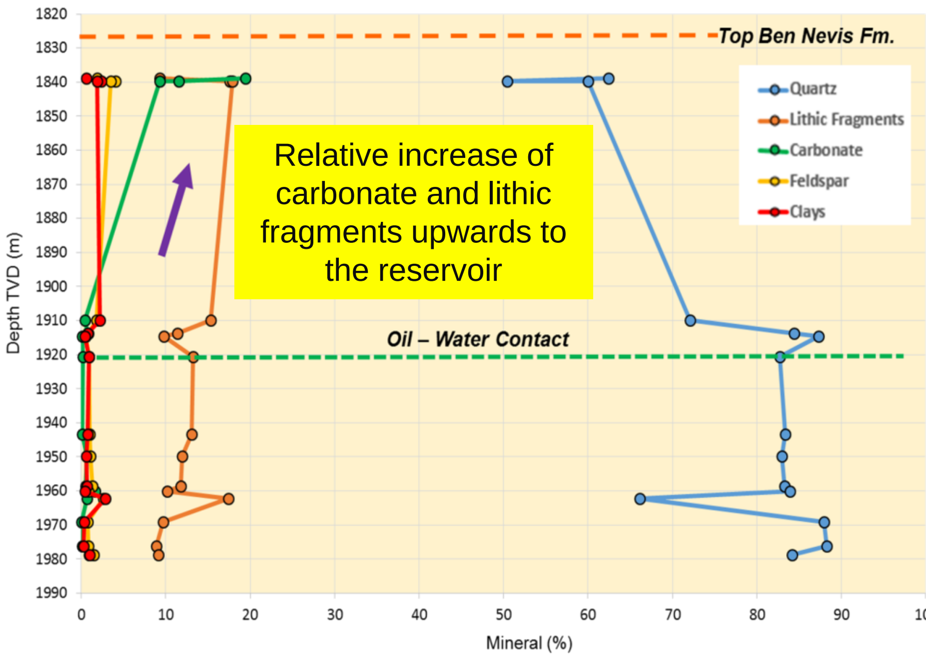
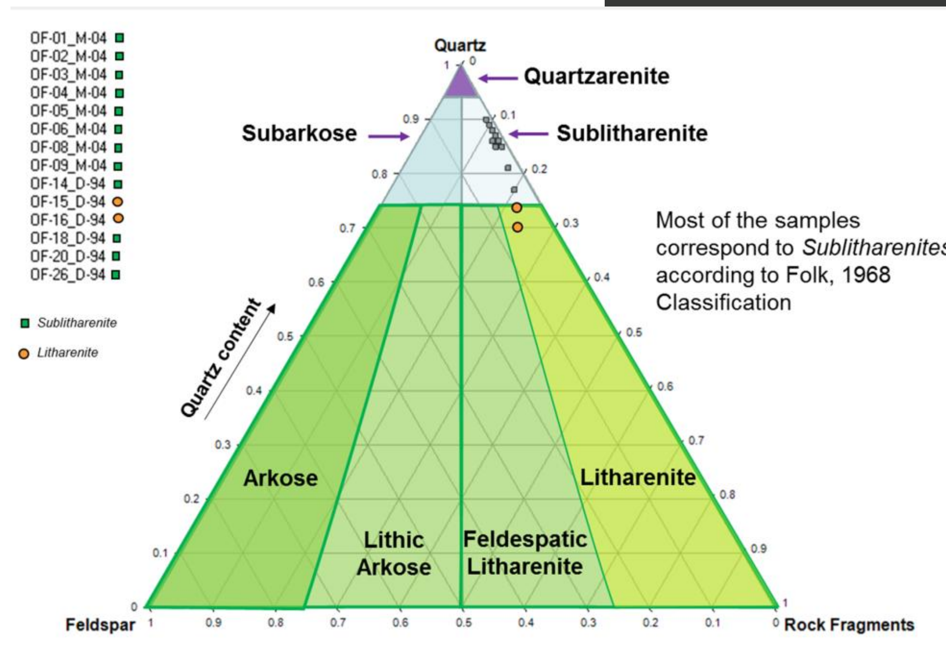
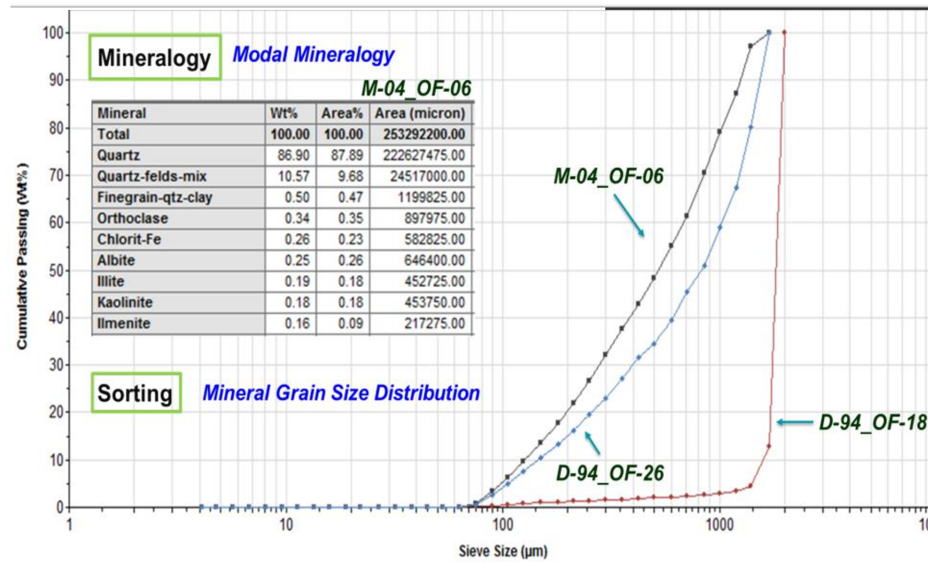


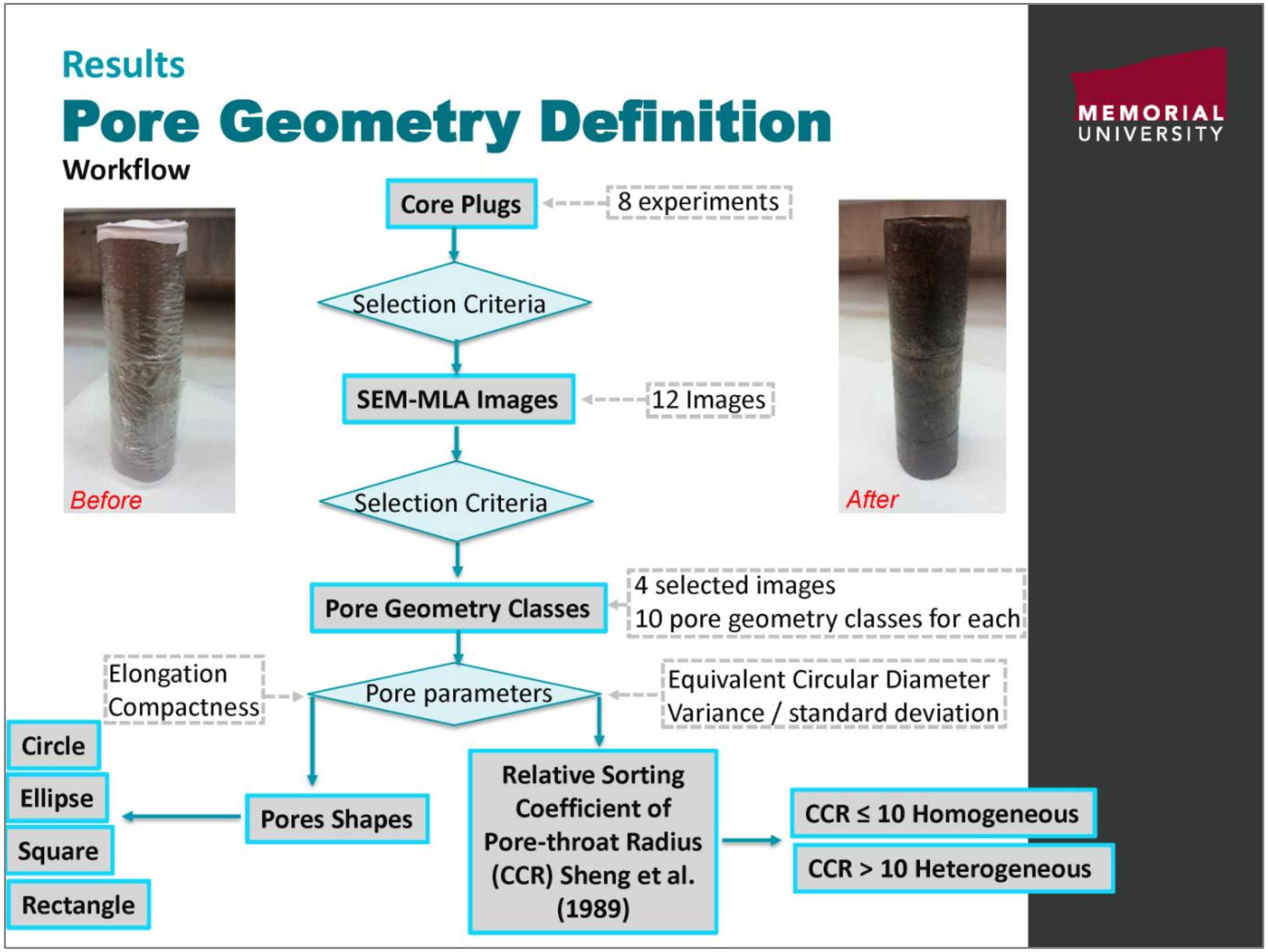




Mineral	Wt%	Area%	Area (micron)
Total	100.00	100.00	253292200.00
Quartz	86.90	87.89	222627475.00
Quartz-felds-mix	10.57	9.68	24517000.00
Finegrain-qtz-clay	0.50	0.47	1199825.00
Orthoclase	0.34	0.35	897975.00
Chlorit-Fe	0.26	0.23	582825.00
Albite	0.25	0.26	646400.00
Illite	0.19	0.18	452725.00
Kaolinite	0.18	0.18	453750.00
Ilmenite	0.16	0.09	217275.00

Integration of minerals analysis techniques allows to characterize Ben Nevis Fm. Sandstones as:

- **Sublitharenites**
- **Fine to medium grain size**
- **Well to moderate sorting**
- **Reservoir quality decrease upwards to the reservoir**



Presenter's notes:

- Selection criteria of core plugs: defined by Plackett-Burman Experiment Design (8 core plugs)
- Selection criteria of SEM-MLA images: 12 images regularly spaced trough the thin section
- Selection criteria Pore Geometry Classes From 4 selected images (based in the average porosity of the core sample) 10 pore geometry classes were defined in each one based on pore-throat representative and mineral association

Results

Pore Geometry Definition

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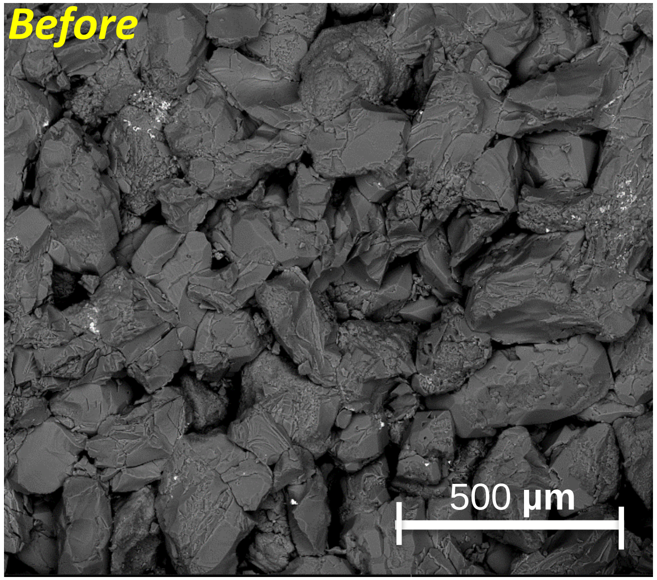
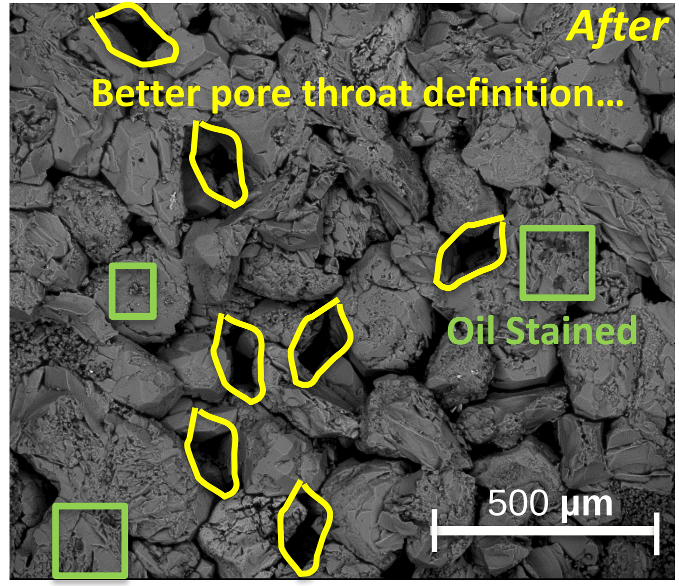
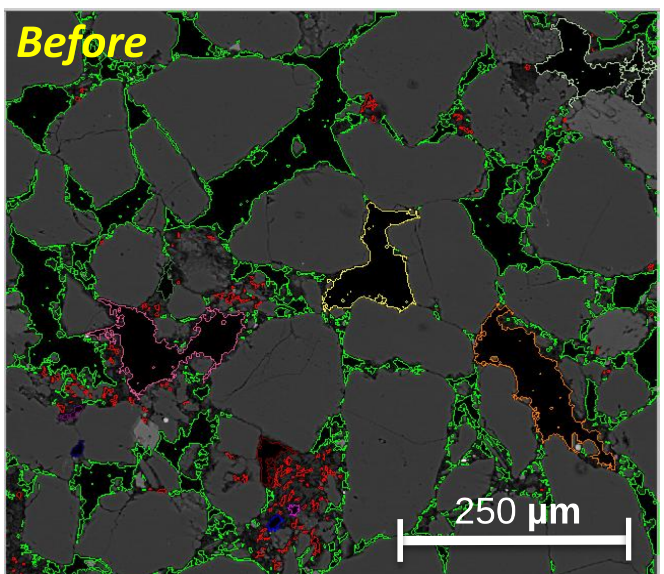
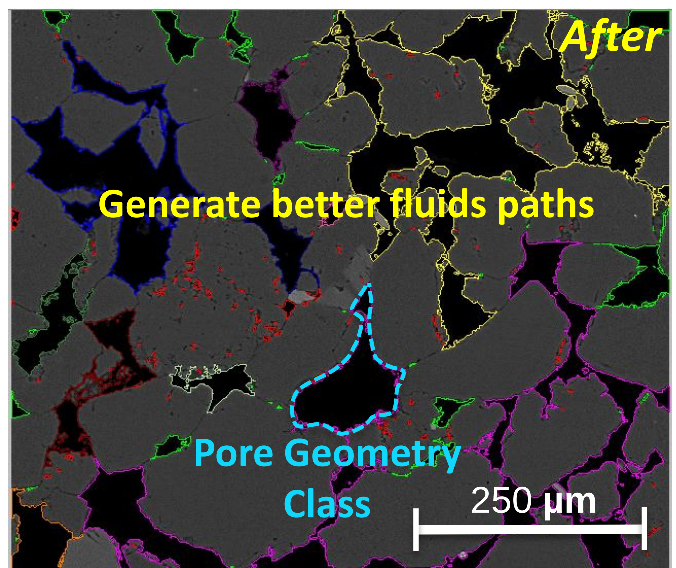




Core Slabs





Polished thin sections

Results

Pore Geometry Definition

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CCR: 12.3 (Heterogeneous)

MLA Results

Mineral	Area (%)
Quartz	94.7
Quartz - Feldespar Mix	3.04
Orthoclase	1.01
Fine grain - Quartz - Clays	0.10
Kaolinite	0.10
Albite	0.06
Perthite	0.04
Fine grain - Quartz - Carbonates	0.03
Calcite	0.03
Illite	0.02
Organic	0.01
Rutile	0.01
Ilmenite	0.01
Muscovite	0.01

CCR: 10.4 (Heterogeneous)

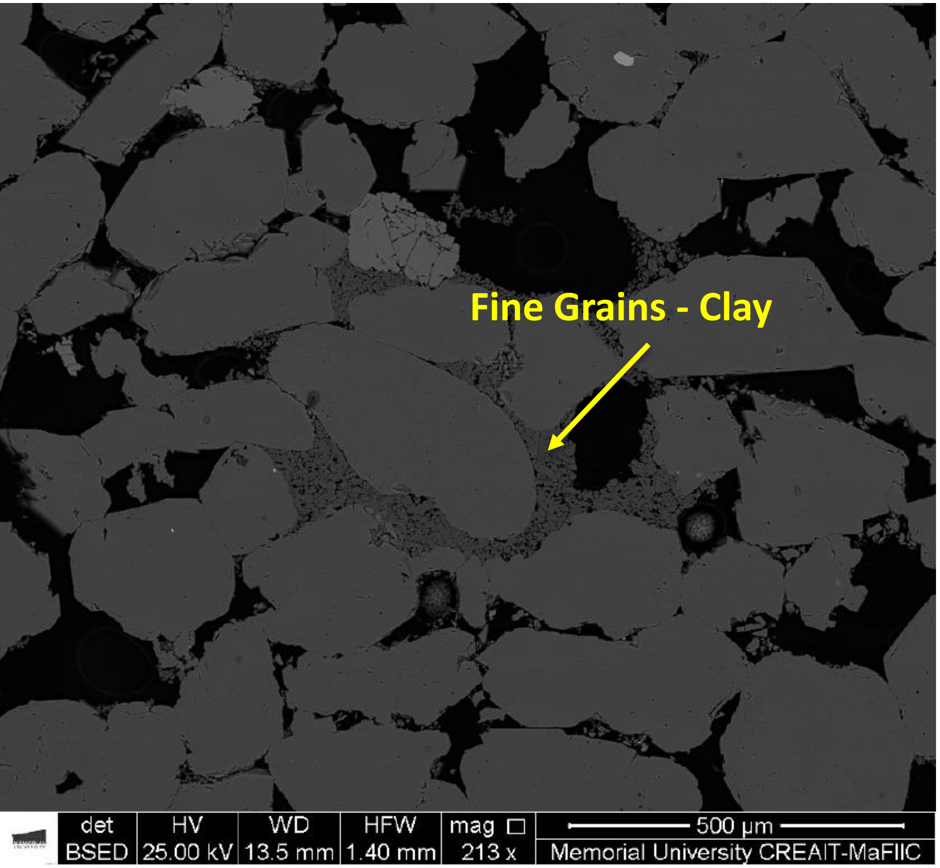
MLA Results

Mineral	Area (%)
Quartz	95.6
Quartz - Feldespar Mix	2.89
Orthoclase	0.88
Fine grain - Quartz - Clays	0.06
Kaolinite	0.07
Albite	0.06
Perthite	0.03
Fine grain - Quartz - Carbonates	0.01
Calcite	0.03
Illite	0.02
Organic	0.03
Rutile	0.01
Ilmenite	0.01
Muscovite	NA

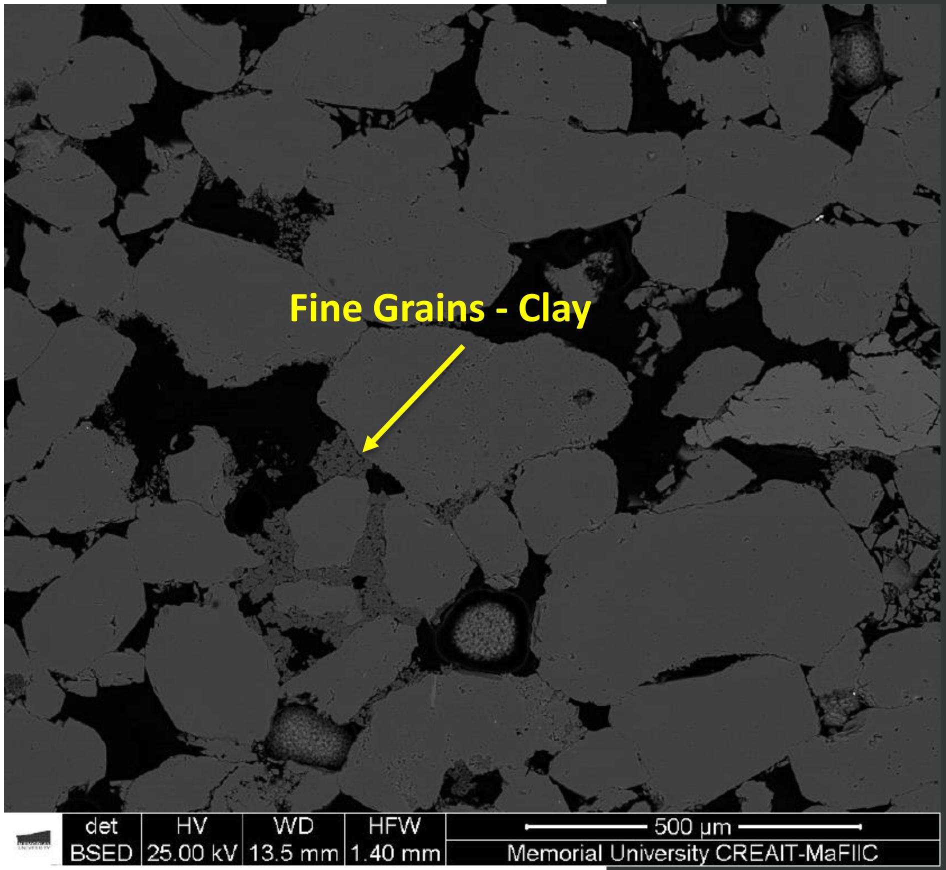
Results

Pore Geometry Definition

SEM Image Before Flooding

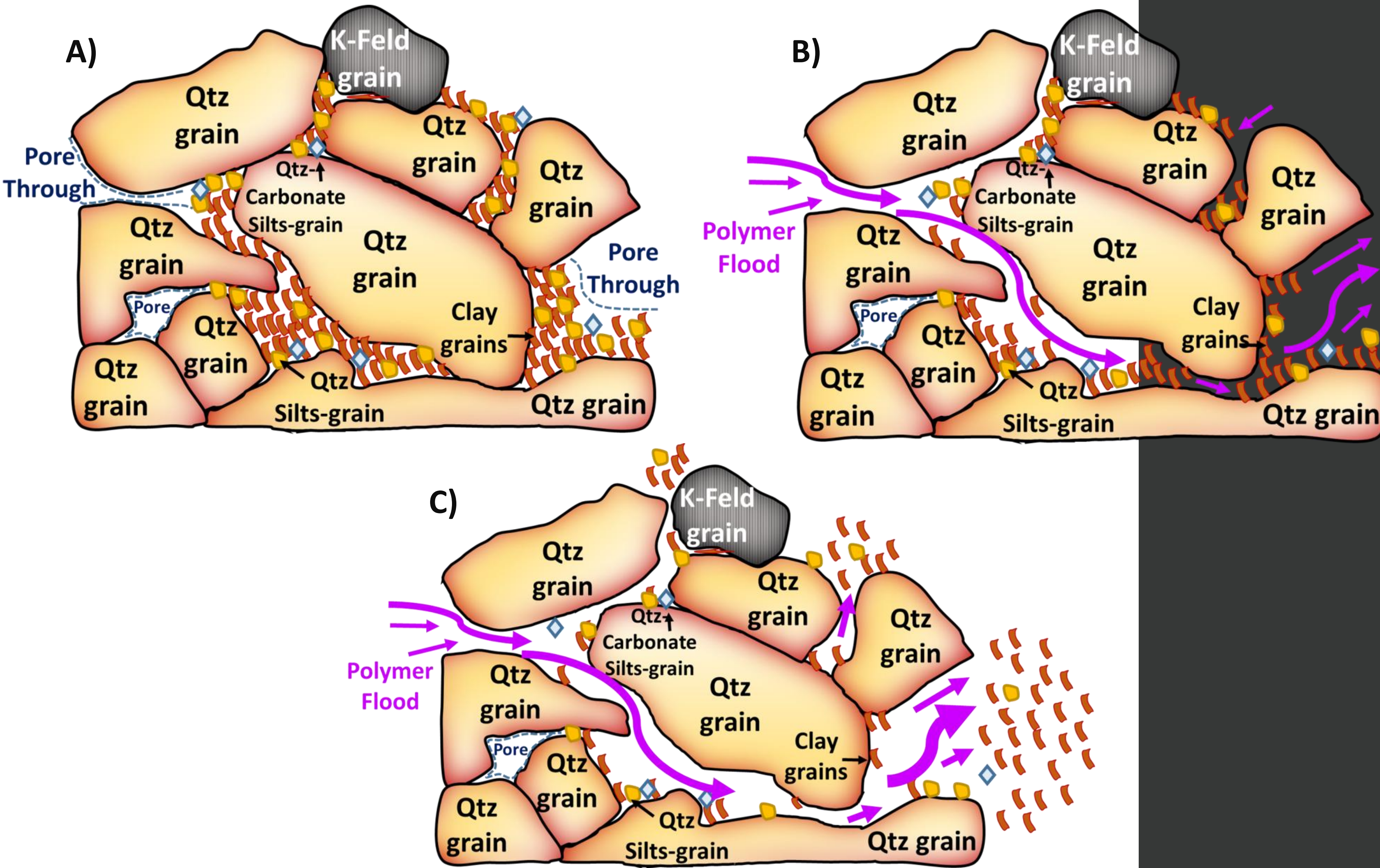


SEM Image After Flooding



Results

Fluid – Rock Interaction Mechanism Model



Conclusions

Pore Changes at Hebron Field

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- Porosity increase and a qualitative permeability rise are observed in the polymer flooded core sandstones samples.
- Intergranular clay matrix detachment and partial removal from the rock sample (due to polymer flooding input/release drag) are the main processes that explain the porosity increase.
- Minor textural changes observed consists of variations in the roughness of grain-pore contacts, pore shape and aspect ratio.
- Primary texture of the rock subjected to polymer flooding injection is an important factor and seems to enhance textural/mineralogical changes in heterogeneous systems; thus affecting the oil recovery

Acknowledgements

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